Volume XXII. *June, 1906.* *Number 6.*

THE

PHYSICAL REVIEW.

MERCUROUS SULPHATE AND THE STANDARD CELLS.

By G. A. Hulett.

THE question as to the best method of preparing the mercurous sulphate and the depolarizer for standard cells does not yet seem to be satisfactorily settled. Mr. F. E. Smith [1] proposes four methods for trial: (*a*) The electrolytic method; (*b*) by adding drop by drop mercurous nitrate to a strong sulphuric acid solution; (*c*) mercurous sulphate is dissolved in strong sulphuric acid and precipitated by diluting; (*d*) by the action of fuming sulphuric acid on mercury at ordinary temperatures. Mr. Smith invites various workers to construct cells according to his specifications and forward them to the National Physical Laboratory where they may be compared. This should give interesting information as to the reliability of the various methods.

H. v. Steinwehr [2] concludes from a few experiments that the principal if not the only cause of the variation of the E.M.F. of standard cells is traceable to a difference in the size of the particles of the mercurous sulphate used as depolarizer. It is well known that a fine-grained sample of a salt has a greater solubility, and therefore its solution will show a greater E.M.F. than the solution of a coarser-grained sample of the same salt. H. v. Steinwehr concludes from theoretical considerations that variable amounts of the

[1] Electrician, 55, 856, 1905.
[2] Zeit. Instrumentk., 20, 205.

hydrolyzed basic salt in the depolarizer could not be the cause of the variations observed in the E.M.F. of standard cells.

Last fall a number of cells were made which give experimental evidence on these important points. The main object of the work was to determine the effect of varying not only the strength of the sulphuric acid used in making the electrolytic mercurous sulphate, but the effect of varying the current density for a given strength acid. Samples of the sulphate were made by passing an electric current from a mercury anode into sulphuric acid. The concentrations of the acid used were .05 molecular, .5 molecular, molecular and 2.6, 3.7 and 12 times molecular, while the current densities were varied from 0.1 amp. to 5 amp. per 100 cm.^{2} mercury anode surface. The details of the method employed in making these various samples will be described below.

Some of the samples were gray and others white. With a low current density the white product appeared while higher current densities gave the gray. The point at which the gray appeared depended also on the strength of the acid used. With 2.6 molar acid the product was gray at a current density of 0.3 amp. and above, while with molecular acid the product was still white with 5 amp. per 100 cm.^{2} surface.

The gray preparation seems to give more uniform results than the white and a slightly lower value of the E.M.F. One is inclined to attribute this grayness to finely divided mercury, probably an "anode slime" which appears only at the higher current densities, but a high power microscope did not with certainty confirm this supposition. If the grayness is due to mercury it must be in an exceedingly fine state of division and would be an advantage as it would tend to prevent the formation of mercuric mercury.

Previous experiences have shown me that the comparison of samples in an *H* cell with a common electrolyte is often misleading, therefore the various samples were actually tested in cells in which all the other materials were the same. Further the cells were kept in a large constant temperature oil bath and compared at frequent intervals for several months. The bath contained 100 liters of kerosene oil and was electrically heated and controlled. The temperature was maintained constantly at 25° C. and has very

seldom varied .02° from that temperature. Certificated thermometers were used to determine the temperature.

The cells were placed in wooden racks, and all the anode wires were joined together while the cathode wires passed up through little glass tubes which extended 15 cm. above the racks, ending near the top of the bath, where they were very accessible. The bath now contains 120 cells, some of them over two years old. The comparisons were made by means of a Feussner potentiometer (built by Otto Wolff, Berlin) and a sensitive D'Arsonval galvanometer. The apparatus worked very satisfactorily, a difference of 0.00001 volt caused a deflection of 2 mm. on the scale. The unit chosen for this and the previous work was the international volt, which is based on the Clark cell made according to the old specifications with an assumed value of 1.434 volts at 15° C.

The cells here considered are of the usual form and were hermetically sealed. The cadmium sulphate used was carefully recrystallized and only the perfectly clear well-rinsed crystals were used. A large stock of 12.5 per cent. cadmium amalgam was made from pure materials, and the mercury was distilled.[1] The cells were made as nearly alike as possible with the exception of the depolarizers to be tested. Precautions were taken to avoid hydrolysis in removing the acid from the various samples of mercurous sulphate, and attention was given to uniformity in making the pastes.

Table I. gives the observations made on these cells, column 1 gives the number of the cell, column 2 the date of construction, column 3 gives the strength of sulphuric acid from which the mercurous sulphate of the depolarizer was made, and column 4 gives for each case the current density employed and is expressed in amperes per 100 cm.^{2} mercury anode surface.

Attention is called to the last six cells (A21 to A25 incl.). The depolarizers of these cells were made from acid of *less* than molecular concentration and the values are higher than the others and are irregular, while all the rest of the cells made from molecular sulphuric acid or stronger than molecular, are in good agreement. There is hardly a suggestion of an effect due to dif-

[1] PHYSICAL REVIEW, 21, 388. 1905.

TABLE I.

Cell.	Date.	Source of the Acid	Hg_2SO_4 D_{100}	Oct. 26.	Nov. 15.	Nov. 18.	Nov. 22.	Nov. 30.	Dec. 10.	Dec. 17.	Dec. 24.	Jan. 1.
A1	Oct. 21	2.7 molar	0.82 amp.	1.01905	1.01905	1.01906	1.01905	1.01905	1.01904	1.01905	1.01905	1.01905½
A2	"	"	"	04	05½	05	04½	05	05	05	05	05
A3	"	"	"	04	06	05	05½	05½	05	05½	05	05
A4	"	"	"	05	05½	05	05	06½	05½	06	05½	05½
A5	"	"	"	05	05½	05	06	05½	05	05½	05	05
A6	"	"	"	05	05	05	06	05½	05½	06	05	05
A9	Nov. 15	"	0.20 amp.			06	02½	02	03½	03	03	04
A10	"	"	1.5 "			05	03	04	04	04	04	05
A32	Dec. 15	12 molar	0.25 "								04	04
A33	"	4 molar	0.25 "								04	04½
A12	Nov. 21	1 molar	1.0 "				07	07	07	07	07	08
A13	"	"	2.5 "				06	07	06	05½	06	07
A14	"	"	5.0 "				04½	07	04	04	04½	05½
A15	"	"	0.2 "				09	11	08	08½	08½	09
A21	Nov. 27	½ molar	0.2 "					16	16	18	17½	15½
A21	"	"	1.0 "					09	08½	08	08	07
A22	"	"	4.0 "					14	15	14	15	14
A23	"	½₀ molar	0.2 "					25	22	19	20	22
A24	"	"	0.5 "					30	26	25	25½	27
A25	"	"	2.5 "					34	30	29	28	26

TABLE I. — *Continued.*

Cell.	Date.	Source of the Acid	Hg_2SO_4 D_{100}	Jan. 6.	Jan. 13.	Jan. 20.	Feb. 1.	Feb. 7.	Feb. 20.	Mar. 4.	Mar. 15.	Mar. 31.
A1	Oct. 21	2.7 molar	0.82 amp.	1.01905	1.01905	1.01904	1.01905	1.01905	1.01905	1.01903½	1.01904	1.01905
A2	"	"	"	05	05	04½	05	05	05	03½	04	05
A3	"	"	"	05	05	04½	05	05	05	03½	04	05
A4	"	"	"	05	05	05	05½	05	05	04	04½	05
A5	"	"	"	05	05	05	05	05	05	03½	04	05
A6	"	"	"	05½	06	05	05	05½	05	04	05	06
A9	Nov. 15	"	0.20 amp.	03	03	03	04	04	03½	04	03½	05
A10	"	"	1.5 "	04½	04½	04	05	05	04½	05	05	06
A32	Dec. 15	12 molar	0.25 "	03	03	04	04	02	02½	00	02	03
A33	"	4 molar	0.25 "	04½	04	06	05	05	05	02	04	04
A12	Nov. 21	1 molar	1.0 "	07½	07½	06½	07½	07½	07½	05	07	08
A13	"	"	2.5 "	06	06	05	06½	06	06	04	06	07
A14	"	"	5.0 "	05½	05	03½	05	04½	04½	02	05	06
A15	"	"	0.2 "	08½	08½	07	08	08½	08	05	07½	08
A20	Nov. 27	½ molar	0.2 "	15	17	15	18	18	17	15	16	17
A21	"	"	1.0 "	08	10	07	08	07	07	06	07	08
A22	"	"	4.0 "	18	19	14	15	14	14	13	14	15
A23	"	$\frac{1}{20}$ molar	0.2 "	21	20	18	20	18	18	17	18	19
A24	"	"	0.5 "	23	24	23	24	23	23	22	23	24
A25	"	"	2.5 "	24	23	24	26	25	23	21	20	19½

ferent current densities used in making the mercurous sulphate, but the strength of the acid used certainly does play a rôle as soon as it becomes less than molecular. This is also the strength acid at which the solubility curve (of mercurous sulphate in varying concentrations of sulfuric acid) shows a sharp break.[1] The solubility is .208 grams of the sulphate in a liter of 4 times molecular acid, and increases to a maximum of .550 grams in a liter of molecular acid. Here the curve takes a sharp turn downward, it is .502 gram in .5 molar and .455 gram in .25 molar and .384 gram of mercurous sulphate in a liter of .05 molar sulphuric acid, all at 25° C.

Molecular sulphuric acid then represents a point of discontinuity in the solubility curve and also for the behavior in cells of mercurous sulphate made from various concentrations of the acid. The principal conclusion to be drawn from the standpoint of standard cells is that, in making mercurous sulphate, one may use any strength of sulphuric acid from molecular to concentrated, and any desirable current density. The results obtained with these cells are very favorable for the electrolytic method of preparing the sulphate, for it must be remembered that for each cell a particular sample of paste was made, requiring separate manipulations. They are, therefore, without the advantage of cells made from one uniform batch of paste.

The question of a possible effect of the size particles on the solubility of mercurous sulphate was considered when the method was devised, and it was found that there was not a measurable effect with the electrolytic preparations. Attention was called to this in the necessary precaution of stirring the system, after the current was broken, so that the very finest particles might disappear.[2]

H. v. Steinwehr has lately[3] called attention to this point and claims for it the principle cause of the variations observed in the E.M.F. of cells. Experimental evidence on this point is contained in Table I. The mercurous sulphate used in each cell was microscopically examined and the size of the particles measured. In the case of the

[1] Hulett, Zeit. Phys. Chem., 49, 494, 1904.
[2] Hulett, Zeit. Phys. Chem., 49, 486.
[3] Zeit. Instrumentk., 25, 205. 1905.

first fourteen cells, or all of those samples of sulphate made from molecular or stronger acid, the particles vary over a wide range, from .002 mm. to crystals .070 × .130 mm. but it will be observed that these cells are all in good agreement.

The samples made from molecular acid were uniformly larger-grained than the other samples. This was to be expected as with this strength acid the sulphate has the maximum solubility. The sample made with .2 amp. was particularly large-grained, and this sample was stirred with the acid and the finest particles decanted until only the very coarsest were left and these were taken for the depolarizer of cell A15. Now it will be seen that the E.M.F. of this cell is not lower but *higher* than the other cells. Furthermore the cells A21 to A25 which have a high value, were constructed with mercurous sulphate made from less than molecular acids, but these samples were decidedly coarser-grained than the samples used in cells A1 to A6. Since finer particles are more soluble, their solution should *increase* the E.M.F. of the cells which are made with the finer-grained depolarizers. Therefore the above results show that the effect of size of particles, in the electrolytic preparations, is not measurable and that whatever deviations there are must have some other explanation.

The microscopic observations made on the samples of electrolytic mercurous sulphate indicated that the higher current densities gave finer-grained but more uniform preparations, and also that the solubility of the sulphate had an effect in the sense that the average size of the particles are smaller in the samples made from the more concentrated acids where the solubility is less. The sample made from 2.6 molecular acid with a current density of 1.5 amp. was carefully examined and found to contain for the most part particles .004 to .008 mm. with few over .010 mm. In all the samples of electrolytic mercurous sulphate examined, comparatively few particles that measured less than .002 mm. were noticed and the failure to find variations in the E.M.F., due to size of particles, with these samples agrees with the work done on the effect of size of particles on the solubility of gypsum and barium sulphate. A measurable increase in the solubility has not been obtained until these powders contained a *large number* of particles of less than .002

mm.[1] Commercial mercurous sulphate is very fine-grained, as has been pointed out by H. v. Steinwehr (*l. c.*), and it is well attention has been called to this question of a possible effect of the size of the particles.

THE QUESTION OF HYDROLYSIS.

The complete removal of the acid from the mercurous sulphate before making the paste is important, as sulphuric acid has a very marked effect on the E.M.F. of the cadmium cell, causing a low value. In removing the acid hydrolysis will take place if water or a too dilute acid is used in washing the sulphate. An acid salt is formed and goes into solution while a slightly soluble basic salt remains mixed with the washed salt.[2] The effect that this basic salt has on the E.M.F. of cadmium cells was tested as follows: Some electrolytic mercurous sulphate was washed with absolute alcohol and thoroughly dried. Part of this was completely hydrolyzed by treating it with successive portions of water.[3] The hydrolyzed and normal salt were then mixed in known proportions. Six samples were made containing respectively .1, .5, 1, 5 and 10 per cent. of the basic salt and these were used in cells A35 to A40 (Table II.). It was found that the effect on the E.M.F. of the cells was not constant but varied with the amount of the basic salt present in the depolarizer. The variation, while not uniform, in general increases with the amount of the basic salt.

When the normal salt is shaken with water the hydrolysis goes to the equilibrium point and stops until more water is added. By using definite amounts of salt and water a known amount of the basic salt is left with the solid. Here the effect is even greater as shown by the cells (A44 to A46). In these cells the sulphate of the depolarizer was formed by stirring normal mercurous sulphate with water and mercury until no further change took place and then the amount of the basic salt in the solid depended on the relative amounts of salt and water taken. In this way samples conatining 1, 3 and 10 per cent. of basic salt were prepared and used in

[1] Hulett, Zeit. Phys. Chem., 37, 385, 1901.

[2] Gouy, Compt. rend., 130, 1399, 1900; Hulett, Zeit. Phys. Chem., 49, 493.

[3] Gouy, l. c.

TABLE II.

Cell.	Date.	Mercurous Sulphate.	Nov. 15.	Nov. 16.	Nov. 22.	Nov. 30.	Dec. 10.	Dec. 17.
A7	Nov. 15	Kahlbaum's mercurous sulphate.	1.02235	1.02208	1.02001	1.01947	1.01936	1.01935
A11	Nov. 19	Kahlbaum's mercurous sulphate rotated with mercury and 1.4 molar acid.				26	22	23
A29	Dec. 3	Kahlbaum's mercurous sulphate rotated with mercury and 3.7 molar acid.					15	15
A30	Dec. 15	Kahlbaum's mercurous sulphate rotated with mercury and 12.7 molar acid.						20
A26	Nov. 27	(Chemically) mercurous nitrate—sulphuric acid 90°.					22	21½
A27	"	(Chemically) mercurous nitrate—sulphuric acid 20°.					20	20½
A28	"	Mercuric sulphate reduced by mercury.					11	10½
A35	Dec. 21	0.1 per cent. basic mercurous sulphate added.						
A36	"	0.5 per cent. basic mercurous sulphate added.						
A37	"	1.0 per cent. basic mercurous sulphate added.						
A38	"	5.0 per cent. basic mercurous sulphate added.						
A39	"	10 per cent. basic mercurous sulphate added.						
A40	"	50 per cent. basic mercurous sulphate added.						
A44	Jan. 5	Mercurous sulphate stirred with 8 parts of water and mercury 1 per cent. basic.						
A45	"	Mercurous sulphate stirred with 75 parts of water and mercury 3 per cent. basic.						
A46	"	Mercurous sulphate stirred with 25 parts of water and mercury 10 per cent. basic.						

TABLE II.—*Continued.*

Cell.	Date.	Mercurous Sulphate.	Dec. 24.	Jan. 1.	Jan. 6.	Jan. 13.	Jan. 20.	Feb. 1.
A7	Nov. 15	Kahlbaum's mercurous sulphate.	1.01935	1.01935	1.01935	1.01934½	1.01933½	1.01934½
A11	Nov. 19	Kahlbaum's mercurous sulphate rotated with mercury and 1.4 molar acid.	21½	24	23½	24½	20½	23
A29	Dec. 3	Kahlbaum's mercurous sulphate rotated with mercury and 3.7 molar acid.	18	21	17	19	20½	22
A30	Dec. 15	Kahlbaum's mercurous sulphate rotated with mercury and 12.7 molar acid.	18	20	23	21	19	21
A26	Nov. 27	(Chemically) mercurous nitrate—sulphuric acid 90°.	21½	21	22	23	29	18
A27	"	(Chemically) mercurous nitrate—sulphuric acid 20°.	19½	20	20	20	17	17
A28	"	Mercuric sulphate reduced by mercury.	12	14	12	12	10	13
A35	Dec. 21	0.1 per cent. basic mercurous sulphate added.		09	10	11	10	10
A36	"	0.5 per cent. basic mercurous sulphate added.		08	08	09	07	07
A37	"	1.0 per cent. basic mercurous sulphate added.		07	07	07	06	05
A38	"	5.0 per cent. basic mercurous sulphate added.		15	14	15	14	13
A39	"	10 per cent. basic mercurous sulphate added.		21	20	21	19	18
A40	"	50 per cent. basic mercurous sulphate added.		46	44	44	41	41
A44	Jan. 5	Mercurous sulphate stirred with 8 parts of water and mercury 1 per cent. basic.				40	35	36
A45	"	Mercurous sulphate stirred with 25 parts of water and mercury 3 per cent. basic.				27	22	24
A46	"	Mercurous sulphate stirred with 75 parts of water and mercury 10 per cent. basic.				61	56	56

TABLE II.—*Continued.*

Cell.	Date.	Mercurous Sulphate.	Feb. 7.	Feb. 20.	Mar. 4.	Mar. 15.	Mar. 31.
A7	Nov. 15	Kahlbaum's mercurous sulphate.	1.01934	1.01933	1.01931	1.01932	1.01933
A11	Nov. 19	Kahlbaum's mercurous sulphate rotated with mercury and 1.4 molar acid.	18½	20	18	22	24
A29	Dec. 3	Kahlbaum's mercurous sulphate rotated with mercury and 3.7 molar acid.	20	19	17	19	20½
A30	Dec. 15	Kahlbaum's mercurous sulphate rotated with mercury and 12.7 molar acid.	19½	19	16	18	18
A26	Nov. 27	(Chemically) mercurous nitrate—sulphuric acid 90°.	17	20	19	20	22
A27	"	(Chemically) mercurous nitrate—sulphuric acid 20°.	15	—	—	17	18
A28	"	Mercuric sulphate reduced by mercury.	11	11	10½	12	14
A35	Dec. 21	0.1 per cent. basic mercurous sulphate added.	09	08	06	07	08
A36	"	0.5 per cent. basic mercurous sulphate added.	06	06	04	05	06
A37	"	1.0 per cent. basic mercurous sulphate added.	05	04	03	03	04
A38	"	5.0 per cent. basic mercurous sulphate added.	12	11	10	10	11
A39	"	10 per cent. basic mercurous sulphate added.	17	16	15	15	15½
A40	"	50 per cent. basic mercurous sulphate added.	39	35	35	33	33
A44	Jan. 5	Mercurous sulphate stirred with 8 parts of water and mercury 1 per cent. basic.	31	30	28	27	27
A45	"	Mercurous sulphate stirred with 25 parts of water and mercury 3 per cent. basic.	20	20	17	17	17½
A46	"	Mercurous sulphate stirred with 25 parts of water and mercury 10 per cent. basic.	49	46	42	41	41

cells A44, A45, A46. Here the effect on the E.M.F. is very marked, and also variable.

It was to be expected that the presence of the basic salt on the depolarizer would increase the E.M.F. of the cell since the salt has a slight solubility but it is surprising that there should be such a marked variation when the per cent. of the basic salt was varied. Any mixture of the normal and basic salts such that both are in excess after the solution is saturated should yield a definite solution that is independent of the relative amounts of the two salts. H. v. Steinwehr used this argument to prove that the basic salt could not cause variations in the E.M.F. of cells. But in view of the above facts one must rather conclude that changes are taking place in this system with the possibility of new phases being formed. Further evidence that the cathode leg of the cadmium cell is not a system in equilibrium will be given in another article.

The similar behavior of the samples containing the basic salt (cells A44 to A46) and those made from less than molecular acid (cells A21 to A25) suggests that hydrolysis begins as soon as the acid becomes less than molecular. One might expect a larger amount of basic salt in the sample made from the diluter acids since hydrolysis, if it occurred, would go on until a solution was formed which would prevent further change. Hydrolysis then would be the explanation of the break in the solubility curve at molecular concentration. Further evidence for this view is that an analysis of a sample of the sulphate made from one half molar acid indicated the presence of a basic salt.[2] The behavior in cells of the samples of sulphates made from less than molecular acids makes it difficult to assume the existence of an allotropic modification as explaining the break in the solubility curve. On the other hand Cox[1] concludes from Gouy's results and some of his own observations, that there is only one basic mercurous sulphate and that the basic and normal salts are in equilibrium with .002 molecular acid. It is evident that more work needed on this question of the hydrolysis of mercurous sulphate.

The results here recorded, however, show that one cannot allow the strength of the sulphuric acid, used in making mercurous sul-

[1] Zeit. Anorg. Chem., 40, 178, 1904.
[2] Zeit. Phys. Chem., 49, 496.

phate for standard cells, to become less than molecular. Until further evidence is at hand on the question just considered, it seems best to keep the mercurous sulphate, to be used in standard cells, from coming in contact with sulphuric acid of less than molecular concentration.

Samples of mercurous sulphate from other sources than electrolytic were also used, and the record of these cells will be found in Table II. Cell A7 was made from Kahlbaum's mercurous sulphate. The paste for this cell was washed with water and made according to the old specifications. It had a very high value at first and required about a month at 25° to reach a fairly constant value, and then it was .00030 v. higher than the cells made with electrolytic sulphate. A few experiments were made to test the effect of treating commercial mercurous sulphate with sulphuric acid and mercury. Samples of Kahlbaum's preparation were stirred twelve hours with sulphuric acid and mercury, using different concentrations of acid (from 1.4 to 12 molar). The pastes were made as described later. Cells A11, A29 and A30 are the ones here considered, and while the method of treatment yields a lower value than cell A7, it is not satisfactory. Probably a longer stirring would give a better agreement and nearer the value given by the electrolytic.

For cell A28 the mercurous sulphate was made by reducing mercuric sulphate by stirring it with mercury and sulphuric acid. The method is simple and has the advantage of producing much finely divided mercury. This cell has given satisfactory results and one similarly made two years ago[1] behaved particularly well from the first, this cell, G3, was under observation for eighteen months.

The mercurous sulphate of cells A26 and A27 was made by adding a strong solution of mercurous nitrate to sulphuric acid which was in excess and did not become less than molecular in strength. These cells are distinctly higher than the cells made with electrolytic sulphate, and higher than others I have made with "chemically" prepared sulphate, some of which were very close to the electrolytic, but never as uniform.

[1] Hulett, Zeit. Phys. Chem., 49, 488.

The evidence given by the above-described cells and also the results of the previous work indicate that the electrolytic mercurous sulphate is the most reliable preparation, and that cells made from it are reproducible to 1 or 2 parts in 100,000. It seems well therefore to give a detailed description of the method of preparation based on the results so far obtained.

THE PREPARATION OF ELECTROLYTIC MERCUROUS SULPHATE.

The accompanying cut represents the essential parts of the apparatus needed. A battery jar some 15 cm. in diameter and 20 cm. tall is well suited to the purpose. Mercury to the depth of 2 cm. is put into the jar and is covered with sulphuric acid to a depth of

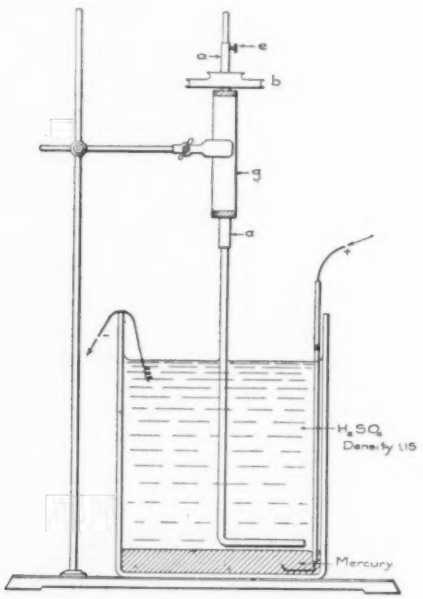


Fig. 1.

15 cm. The strength of the acid used may vary over a considerable range as has been shown. The formation of the sulphate removes an equivalent amount of acid and for several reasons it is best to use 2 or 3 times molecular. If one volume of strong sulphuric acid (1.84 density) is poured into six times its volume of

water, the strength will be about 2.6 molecular. If the acid is made by density it should be about 1.15, and with the two liters used in the jar one may prepare several hundred grams without reducing the strength of the acid to 2 times molecular.

In order to insure contact with the mercury a stiff platinum wire (.8 mm. or over) is sealed into a glass tube with the free end 4 or 5 cm. long. This platinum wire is bent at right angles and extends well out into the mercury when the glass tube is clamped in position. The object of this is to insure contact with the mercury when the solid sulphate collects in the angle of the jar under the mercury. The copper wire from the positive pole of the battery is pushed down inside the glass tube, contact with the platinum wire is insured by running in a little mercury.

A platinum wire suspended in the acid serves as cathode. Here one needs a small surface and large current density in order that much hydrogen and relatively little mercury may be deposited. The solubility of mercurous sulphate in 2.6 molar acid is .4 gram per liter, and with the above arrangement the yield is very good, about 9 grams per ampere-hour.

A motor-driven stirrer is necessary and it is important that the bearings work smoothly. The sketch represents a very simple arrangement. A brass tube (*a*) 8 mm. in diameter is provided with a pulley wheel (*b*). This tube holds the glass stirrer which is made fast by the set screw (*c*), the brass tube turns in the iron bearings which are soldered into the ends of a larger 15 mm. diameter brass tube (*g*). This outer-bearing tube may be clamped in any ordinary clamp. A glass rod that fits the inner brass tube is selected and clamped in the tube. The glass rod extends about 40 cm. below the holder and is bent at right angles. The stirrer is adjusted to the jar so that the *L* part of the stirrer just escapes the mercury when rotating at a rate of about 200 revolutions per minute. Some experience is necessary to adjust the stirrer properly, if the mercury is unduly disturbed much of it will become finely divided and be troublesome.

After all is in order and the stirrer working smoothly, the current is turned on and as soon as the acid is saturated the solid sulphate will appear on the surface of the mercury and form a skin which

does not always break up at once. This difficulty, which happens only when fresh acid and mercury are used, may be avoided by making and breaking the current several times until the solid appears throughout the acid after which no further trouble will be experienced. A current of 2 or 3 amperes may be used and will form some 25 grams an hour. The rapid stirring will keep the mercury surface sufficiently free of the solid until some 50 grams have formed, if more is needed it is best to remove the sulphate and start again, using the same acid and mercury but not allowing the acid to get much below 1.15 in density.

When sufficient mercurous sulphate has formed, the current is broken and the motor stopped. After the solids have settled most of the liquid is decanted (some of it in a wash bottle for assisting in the operations of transferring the solids). The solids and mercury are transferred to a large separatory funnel and the mercury removed. The sulphate finely-divided mercury and about a liter of the liquid are returned to the jar, or run into a large Erlenmeyer flask, and stirred over night. The object of this stirring is to allow the sulphate to become coarse-grained and unless most of the mercury is first removed the sulphate will often collect under it and the action is retarded. After twelve hours' stirring the sulphate settles rapidly and leaves the liquid perfectly clear. The product is still quite gray and is to be kept under the acid from which it was made and protected from the light. It is well to take precautions to protect the sulphate from the light during all the operations.[1]

PREPARING THE PASTE.

The results here recorded show that the basic salt, formed by treating mercurous sulphate with water or too dilute acid, effects the E.M.F. of the cell when it is present in the depolarizer. A

[1] The effect of light is to turn the sulphate brown and then black. Just what change takes place does not seem to be known. Two years ago a cell was made up with this blackened sulphate and had a value of 1.02038 (25°) to start with and decreased all the time it was observed (four months). At the same time some cells were made and half of them were protected from the light, by covering with asphalt paint and shellac, but in a year's time there was no distinct difference between the cells. The brown seems to form only on the surface next to the glass and it seems probable that with ordinary usage there is no effect after the cell is made, but the mercurous sulphate should not be exposed to strong light before it is put into the cell.

higher value is obtained than when the normal salt alone is used, and the effect varies irregularly with the amount of this basic salt present in the deplorarizer. Until this anomaly is cleared up it seems best to avoid the basic salt all together.

The old method of washing the salt with water gave quite uniform results when the cells were made from a particular sample of sulphate, and with a uniform preparation like the electrolytic mercurous sulphate, the old method of washing might do very well. One point is however to be considered, if water is passed through the sulphate in a filter the top layer only turns yellow, evidently the water becomes saturated with the soluble products of hydrolysis and is no longer capable of effecting the lower layer.[1] This top layer has always been rejected and thus the part taken may have contained very little basic sulphate, but the liquid which could not be entirely removed is distinctly acid.[2] Last year a cadmium cell was made in which the solution was .2 molecular sulphuric acid saturated with cadimum sulphate. This cell has always been low, and has now a value of 1.01845 (25°). Acid seems to have more effect than other impurities and is to be avoided. Jaeger & Wachsmuth.[3]

The problem then is to completely remove the acid and to avoid hydrolyzing the salt. This may be done by washing with alcohol, and then once or twice with cadmium sulphate or zinc sulphate solution, as the case may be. For half a dozen cells, or less, one may use a Gooch crucible and Bunsen filtering flask. A little filter is cut from filter-paper with a large cork borer, and fitted to the crucible. The sulphate is brought into the crucible and the acid removed as completely as possible by suction, then some absolute alcohol is run in so as to wash the sides of the crucible and then drawn through the sulphate by suction. This is repeated five or six times, using only a few c.c. of alcohol each time. The alcohol is removed by washing once or twice with a saturated solution of cadmium or zinc sulphate as the case may be.

The washing with alcohol is much more rapid and in general more effective than with the rather viscous sulphate solutions. If

[1] Zeit. Phys. Chem., 49, 497.
[2] L. c., 497.
[3] Wied. Ann., 59, 586, 1896.

the sulphate is washed only with the alcohol and the paste made without completely removing the alcohol the results are good, but it is best to finally wash once with the saturated sulphate solution to be used in making the paste. In washing larger amounts one may use a small Buchener funnel and filtering flask. For thorough washing it is best not to have the sulphate over 2 cm. deep.

The washed sulphate is mixed with about one fourth its volume of finely-powdered cadmium sulphate or zinc sulphate as the case may be and then the saturated solution is added with stirring until a homogeneous paste is formed. The paste should be of such a consistency that it will just flow from a tube 5 mm. in diameter. The paste may be drawn up into such a tube by slight suction and then easily and neatly introduced into the cell. The addition of mercury is not necessary with the gray electrolytic mercurous sulphate.

In the case of the cadmium cell the paste should be over one centimeter deep in the leg of the cell. A number of cells have been made with less than a centimeter of paste, some only a few mm., and they were very irregular and are now very low. The question of the changes in the cathode leg of the cadmium cell, after it is constructed, will be reported on in a succeeding article.

Dr. M. A. Hunter assisted in constructing the cells and in making the comparisons described in this article, and I take this opportunity to thank him for very valuable aid.

PRINCETON UNIVERSITY,
March, 1906.

IMPROVEMENTS IN THE DIFFRACTION PROCESS OF COLOR PHOTOGRAPHY.

By Herbert E. Ives.

THE diffraction process of color photography, invented by Professor R. W. Wood, was first described in the *Philosophical Magazine* for April, 1899. An application of the "three-color" method of reproducing colors by photography, its distinguishing feature is the elimination of pigments as a means of producing the three primary colors, red, green, and blue, and the use, in their place, of diffraction gratings.

The production of color by the grating is utilized in the following manner: A bright point or line of light is focussed on a screen by a convex lens, over which is placed a diffraction grating. Viewed from a point in one of the resulting spectra the lens appears uniformly illuminated in the color of light incident on the eye. By choosing gratings of different spacings any desired color may be obtained at any chosen point. Consequently if the three-color positives are made in the form of diffraction gratings of three different spacings, such that one sends red, the second green, and the third blue light to the same point, the eye placed at that point will see each picture in its appropriate color, and a color picture will result from the summation of the effects of the three.

To produce diffraction color photographs Professor Wood used the bichromated gelatine process. On a glass surface so sensitized three prints were made, one over the other, from the three-color positives, each positive being placed over a glass diffraction grating of suitable spacing in contact with the gelatine surface. From the pictures obtained in this way copies could be made in turn by contact printing on other bichromated gelatine plates.

Although a process of great theoretical interest and of apparent simplicity, during the last six years all attempts to secure satisfac-

tory pictures by the procedure outlined resulted in practical failure. The few pictures obtained were extremely interesting, as some color effects were reproduced with surprising fidelity. Far from being a simple and exact method of reproducing colors, however, the diffraction process proved in practice disappointing. It was difficult to work and quite unreliable, certain color effects were reproduced only occasionally or not at all, while an identical procedure would produce quite different results with different subjects.

Through the courtesy of Professor Wood the writer was last summer furnished with a number of diffraction gratings ruled on the Rowland engines at Johns Hopkins University. With these experiments were made in diffraction color photography, certain defects were discovered in the previous mode of working, means were found for obviating these defects, and the process thereby made to yield results of a hitherto unattainable beauty and perfection.

The fundamental defect in the original mode of making diffraction pictures was found to lie in the means for obtaining the united action of the three gratings, namely, by superposition. In order for the process to be successful each grating should act independently after superposition on the others. As a matter of fact, disturbing effects are introduced by the action of the gratings on one another. In the first place, superposition of two gratings results in a new grating of a coarser spacing whenever any simple relation exists between the two spacings. For instance, when two gratings are ruled on the same dividing engine by a change in the number of teeth "feed," regularly recurring coincidences are found on superposition, these constituting the new grating. In the second place, even when there is no simple relation between the spacings of two gratings, one acts on the other to form "ghosts" or spectra of spectra. In diffraction picture work the first effect causes light to be subtracted from the spectra used and deviated into new unused ones. Hence two colors will not add to produce a color of double luminosity. This was exhibited by the production of dirty yellows and other mixed colors. The second effect, besides occasioning loss of light, causes false color, as the "ghosts" fall in such positions that the eye receives from them different colors than from the original gratings. This case occurred frequently in practice, red

and blue discs combining to form green instead of purple, and pink roses reproducing as green.[1]

The conclusion from these observations was that the grating effects must be added by some means other than superposition. This means was suggested by the Joly process, in which the mixture of the three colors is accomplished by breaking up the picture into narrow juxtaposed lines, alternating red, green and blue, the eye blending the three. Some experiments had previously been made by Professor Wood with Joly pictures, with the object of demonstrating the possibility of making the color lines much finer, by using strips of grating, than is possible by using pigments. For this purpose he ruled a special grating consisting of several lines of one spacing, followed by several of a second and several of a third, repeating across the plate, the width of the strips corresponding to that of original Joly pictures. By printing through this grating from the special line pictures, diffraction Joly pictures were obtained. This procedure was however open to the great disadvantage, apart from the necessity for the specially ruled grating, of dependence upon the specially made Joly originals, of a coarse spacing of lines determined by the limitations of the taking process. A much more serious objection, however, was found by the writer, namely that the lines of the picture, since they ran parallel to the diffraction grating lines, could not be made fine enough to be invisible without themselves forming a diffraction grating, throwing its spectra on those from the three principal gratings and degrading the colors.

The problem was thus reduced to finding some simple and convenient means of breaking up the picture into narrow strips of diffraction grating, and at the same time eliminating the grating effect of these strips. This was achieved by the following procedure:

In Fig. 1, which represents the method of making the improved diffraction pictures, *A* is the bichromated gelatine plate, rigidly fixed

[1] These secondary spectra were mentioned as being "rarely troublesome" by Professor Wood in Nature, October 20, 1904. In the writer's experience the conditions necessary for the best photographic copying of gratings are precisely those to give strong "ghosts."

in position; B is a glass diffraction grating; C is a screen ruled with at least two hundred opaque lines to the inch, the opaque lines being twice the width of the transparent spaces between; D a lens, and E a three-color positive. The latter is one of a set of ordinary three-color positives, containing no lines, and the grating is an ordinary continuously ruled one, also from a set of three, each of which is calculated to send one of the primary colors to a given point, say 2,400 lines to the inch for the red, 3,000 for the green, 3,600 for the blue. With say the "red" positive at E and the corresponding grating at B, an exposure is made, resulting in a series of narrow exposed strips on which the grating structure is impressed. A second positive is then placed at E, the corresponding grating at B, and the ruling C is moved the width of a transparent portion. A second exposure is made, the first exposure being shielded by the opaque lines of the screen, and then a similar treatment given to the third positive. On development a picture is obtained made up of alternating strips of three different grating spacings.

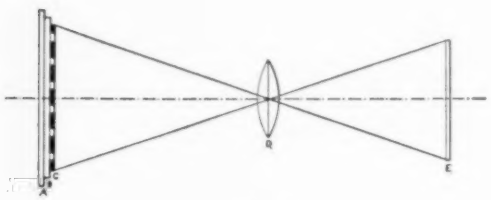


Fig. 1.

To eliminate the grating effect of the narrow strips of grating or Joly lines the latter are made to run at right angles to the diffraction grating lines so that the spectra produced by them are diverted in another direction and do not enter the eye.

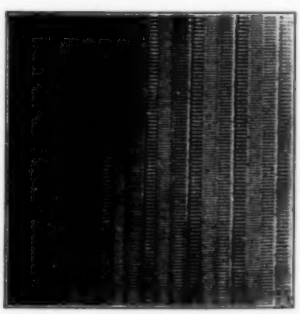


Fig. 2.

Fig. 2 is from a photo-micrograph of a portion of the finished picture. The short fine lines are the diffraction grating lines producing the three primary colors, 2,400 to the inch for the red, 3,000 for the green, 3,600 for the blue. The broad strips at right angles to the diffraction lines constitute the Joly lines, of which there

are 200 groups of three to the inch. From these pictures, it is important to note, an unlimited number of copies can be made by simple contact printing on bicromated gelatine.

As a further modification of the original method the writer has found it possible to obtain the color effects with a single grating spacing. To do this the source of light must be a rather long slit. Viewed through a grating the slit of course gives long spectra. If now the grating be rotated about the perpendicular joining it with the slit the spectra move in toward the latter. By suitable rotation any desired color may be obtained at any given point. With a grating of 3,600 lines to the inch to give the blue when parallel to the slit, a rotation of 21½° will give the green, of 42° the red. In the absence of suitable dividing engines to rule three properly proportioned gratings this affords an exact and easy method of securing the three colors. It has the further advantage that in printing copies any defect in printing contact will affect all three colors alike, which is not the case with gratings of different degrees of fineness. Pictures made with but one grating can of course be broken up into strips precisely as those from three gratings.[1]

With these improvements probably the last word has been said on the pictures themselves. An important improvement in the means for observing them, due to the writer's father, Mr. Frederic E. Ives, must be described.

The lens and distant source of light, as used by Professor Wood, is not a convenient arrangement, nor is it desirable to use artificial light. A convenient apparatus, easily set up, not liable to get out of order, and suitable for daylight, became a necessity upon the development of the picture-making process. The instrument about to be described admirably fulfils this purpose.

The chief difficulty attending the use of daylight for diffraction pictures is lack of light. The light diverted into one spectrum by a grating is at best only a small fraction of the total, and if the

[1] Since working out the above plan the writer has learned that Mr. Thorp, of Manchester, proposed the use of a single grating some years ago. Mr. Thorp's method, however, was to use three sources of light, turning the gratings till they found their own sources and cleared the others, then moving the sources till the desired color was obtained. He found an inclination of ten degrees convenient. The idea of using a definite rotation, calculated from the wave-length of the desired color is, it is believed, new.

sky is used as source this small fraction is not enough to be satisfactory. This difficulty has been overcome by the novel device of a series of slits, each furnishing one spectrum. In this way with four slits, two first and two second order spectra are utilized, giving at least three times the light obtainable from one slit. The use of second order as well as first order spectra, it may be noted, is a distinct advantage, in that, as gratings never give a perfectly uniform distribution of light and color, certain desirable qualities of the picture are often found in one order and not in the other, and the best possible results follow from blending the two.

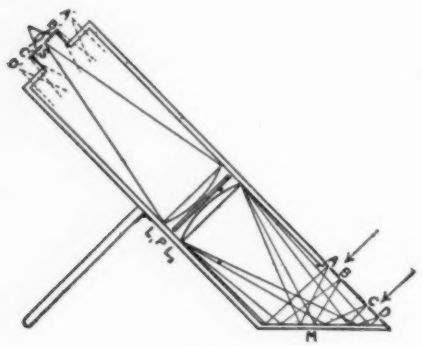


Fig. 3.

Fig. 3 gives the instrument in section, its size being about fifteen inches by three by three. A, B, C, D are the four slits; M a mirror; L_1 and L_2 lenses; P the diffraction picture (a two and a half inch circle); and S the slit through which the picture is observed. The direct images of the slits are formed at A', B', C', D'; from each of these light is diffracted to S; from B and C the first order spectra, from A and D the second order. The instrument can be made either monocular or binocular — the latter form being made possible by a horizontal disposition of the grating lines and slits.

Pictures made in the manner described are entirely free from the defects found in those previously made. Viewed in this instrument they fairly rival the results obtained in the Krōmskōp.

In conclusion the writer wishes to express his thanks to Professor Wood, not only for the original loan of gratings, but for suggestions and assistance in the past winter, during which new gratings have been ruled and much detail work done in perfecting the process. He is also greatly indebted to Mr. Max Levy, of Philadelphia, on whose ruling machines the special opaque line screens have been ruled.

PHYSICAL LABORATORY,
JOHNS HOPKINS UNIVERSITY.

ON THE MEASUREMENT OF THE INDEX OF REFRACTION BY THE INTERFEROMETER.

By John C. Shedd and Philip Fitch.

ONE of the simpler applications of the interferometer is that in which the instrument is used for the measurement of the index of refraction. The method, as heretofore presented, is illustrated in Fig. 1, where M is the mirror of the interferometer which is mounted on the movable carriage, and N the thin lamina whose index is to be determined. If M be first adjusted for color fringes then the introduction of N will increase the optical path by the the amount $e(\mu - 1)$ where e is the thickness of the lamina N.

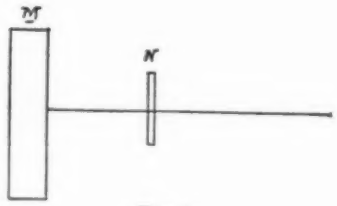


Fig. 1.

This increase in path may be measured by counting the number of fringes passed over in restoring the color fringes to the field as seen through N. If n be this number and λ the wave-length of the light used, then,

$$e(\mu - 1) = n\lambda$$

and

$$\mu = 1 + \frac{n\lambda}{e}. \qquad (1)$$

Generally, but not necessarily, the light passes through N twice and the above equation becomes,

$$\mu = 1 + \frac{n\lambda}{2e}. \qquad (2)$$

The value of n in this case is, of course, twice as great as in equation 1.

The operation of this method may be more fully outlined as follows: *First*, the thickness of the lamina N is carefully measured by

means of a micrometer-screw or optical lever. *Second*, the interferometer is adjusted for color fringes and the lamina is placed in the path of the rays passing to and from the mirror M (Fig. 1) in such a manner as to cut them orthogonally. The mirror M is now advanced until the color fringes appear in the field as seen through N. During the movement of the mirror the number of fringes passed over is counted and the index determined from the data thus secured.

If v = the velocity of light in air,
v' = the velocity of light in the lamina N,
λ = the wave-length in air of the light used (*e. g.*, Na light),
μ = the index of refraction of N,
e = the thickness of N,
n = the number of fringes passed over.

Then $v't = e$, also $vt = e + n\lambda$.

But

$$\frac{vt}{v't} = \frac{v}{v'} = \mu,$$

and hence

$$\mu = \frac{e + n\lambda}{e} = 1 + \frac{n\lambda}{e}. \qquad (1)$$

If the light pass through N twice, then,

$$\mu = 1 + \frac{n\lambda}{2e}. \qquad (2)$$

The objection to this method lies in the fact that e must be determined by some mechanical device. If the micrometer screw be used there is the liability of compressing the lamina in making the measurement. If on the other hand the optical lever be used a lamina of considerable size and uniformity in thickness must be used. The degree of accuracy of either method of getting e is of course far less than in measuring the retardation by counting fringes.

In the present modification of the old method it is proposed to measure e by means of the same light waves which are used for getting the retardation. The same degree of accuracy is thus had in the determination of all of the terms entering into the final equation.

To accomplish this it is necessary that the lamina be of uniform thickness and that a part of its surface be silvered. The thickness of the silver film is not important, as it is measured and allowed for. To secure uniformity of thickness the lamina is introduced into the path of the interferometer, as shown in Fig. 1. Any inequality in thickness or any strain of any sort is shown by a distortion in the fringes. It is thus very easy to select a lamina of uniform optical structure. Having secured such a lamina it is silvered in the ordinary manner, the silvering being then removed from all of one side and half of the other. It is now pressed against the mirror *M* as shown in Fig. 2. A gentle pressure is sufficient to make the lamina adhere to the surface of the mirror. Care must be exercised to apply this pressure to the center of the silvered surface *S*, so that close contact shall be made at this point. In practice it has been found that the fringes, whether chromatic or otherwise, seen from this silvered surface are always circles. This would indicate that the small surface of the lamina is in the form of a concave mirror of very slight curvature.[1]

Having the lamina in place there are now three surfaces on which fringes are to be observed, first, from the surface of the mirror *M* (see Fig. 2) outside of the lamina; second, from the surface *M*

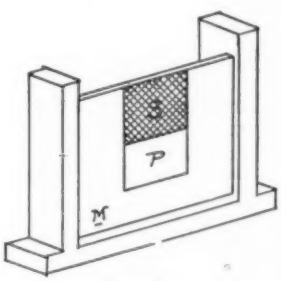


Fig. 2.

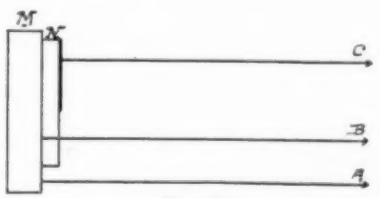


Fig. 3.

through the lamina (*P*, Fig. 2); third, from the silvered surface of the lamina (*S*, Fig. 2).

The readings to be taken are as follows: *First*, the chromatic fringers are secured on the mirror *M*. This will be the position of the ray *A*, Fig. 3. *Second*, the chromatic fringes are secured from

[1] For circular chromatic fringes see PHYS. REV., Vol. XI., page 310.

the surface of the silver film S. This is the ray C in Fig. 3. The number of fringes counted in passing from M to S is a measure of the thickness of the lamina plus the silver film. *Third*, the count is taken back to M, and lastly the number of fringes is counted until the chromatic fringes are seen coming from M through the lamina. This count gives the retardation due to the lamina.

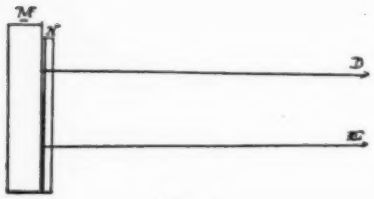


Fig. 4.

The lamina is now removed and replaced with the silvered side next the mirror as shown in Fig. 4. If now the adjustment be made so as to give the chromatic fringes from the mirror M through the lamina, and the count be taken from this position (ray D, Fig. 4) until the fringes appear from the silver film (ray E, Fig. 4) the number of fringes passed over gives the thickness of the silver film.

Let :

n_1 = the number of fringes counted in passing from A to C, in Fig. 3.

n_2 = the number of fringes counted in passing from A to B, in Fig. 3.

n_3 = the number of fringes counted in passing from D to E, in Fig. 4.

λ = the wave-length of the light used for getting the fringes.

Then we will have :

$n_1\lambda$ = twice the thickness of the lamina and the silver film,

or

$$n_1\lambda = 2(e + e').$$

Also :

$n_2\lambda$ = the retardation due to the lamina,

or

$$n_2\lambda = 2e(\mu - 1).$$

Also :

$n_3\lambda$ = twice the thickness of the silver film alone,

or

$$n_3\lambda = 2e'.$$

Therefore

$$(n_1 - n_3)\lambda = \text{twice the thickness of the lamina alone,}$$

or

$$(n_1 - n_3)\lambda = 2c.$$

Finally,

$$n_2\lambda = 2c(\mu - 1) = (n_1 - n_3)\lambda(\mu - 1),$$

or

$$n_2 = (n_1 - n_3)(\mu - 1).$$

So that:

$$\mu = 1 + \frac{n_2}{n_1 - n_3} \qquad (3)$$

It is seen that in equation 3 all of the terms are gotten by counting fringes, and are not dependent upon any mechanical devise whatever.

In the practical working of the method the following suggestions will be found useful:

I. It will be found convenient to have cross wires placed on the lens which is used for giving parallel light to the interferometer. The images of these cross wires serve as an index in counting the fringes. The intersection of the wires should cut the center of the circular fringes.

II. After the lamina has been placed against the movable mirror it generally happens that the stationary mirror of the interferometer must be readjusted in order to secure the fringes. In making this adjustment three sets of fringes should be simultaneously present, those from the silvered surface of the lamina, those seen through the lamina and those from the free surface of the mirror. This can best be done by first securing the circular fringes from the silvered surface of the lamina and then shifting these about until the others appear.

III. The thickness of the lamina tested by the writers did not exceed .2 mm. The accuracy of the method rather increases with the thickness of the lamina used, though the counting is thereby made more tedious. The thickness of the lamina tested measured a little greater when measured by wave-lengths than when measured by the micrometer. This is to be expected when it is considered that the latter method involves a pressure on the lamina.

The following experimental data will illustrate the results to be obtained by this method. The source of light used was the Na flame.

	n_1	n_2	n_3	μ
Glass.	598	306	11	1.521
	601	307	11	1.520
	601	308	11	1.522
Mica.	379	224	9	1.605
	380	224	9	1.603
	380	223	9	1.601
	382	224	9	1.600
	380	224	9	1.603

PHYSICAL LABORATORY,
COLORADO COLLEGE, March 5, 1906.

CONCERNING THE TEMPERATURE OF THE NERNST LAMP.

By Leon W. Hartman.

THE early determinations of the temperature of the incandescent glower of the Nernst lamp gave values which were undoubtedly much too high. These determinations were based on the law of the radiation from a black body. To this class of radiators, however, the Nernst glower does not belong; so that if the glower emits selective radiation as compared with the radiation from a black body, its measured black body temperature might be much above its actual temperature. This is the case; hence the higher values of its temperature, as found by the early investigators, is explained.

If one avails himself of existing data and methods and applies the data and curves of Ångström [1] to the data of the writer,[2] published in a former number of this journal, a value of the temperature much lower than that cited by Lummer and Pringsheim [3] will be obtained. This discrepancy then makes a determination of the temperature of the incandescent glower by direct measurement very desirable.

When the data for the energy losses from incandescent platinum wires in air had been obtained,[4] an effort was made by the writer to utilize the same method for determining the temperature of the incandescent glower of the Nernst lamp. Briefly stated, this method was as follows: The candle power per unit length for varying power supply was first determined with a number of Nernst glowers. In front of an iridium furnace containing a piece of magnesium oxide, was then mounted a frame for the glowers, in series with which was a suitable regulating rheostat. When the furnace was heated, the magnesium within was heated up to incandescence.

[1] Ångström, Phys. Rev., 17, p. 302, 1903.
[2] Hartman, Phys. Rev., 17, p. 65, 1903.
[3] Lummer and Pringsheim, Verhd. d. Deutsch. Ges., 3, p. 36, 1901.
[4] Hartman, Phys. Zeitschr. 5, p. 579, 1904.

Each glower in turn was then mounted on the frame and heated by a current until its color, as seen against the magnesium oxide as a background, seemed as near the color of the latter as it was possible to get it. Noting the power supply, the candle power per centimeter length could be determined from the plotted curves of the first set of observations. As soon as the power supplied was determined, the temperature of the interior of the furnace, *i. e.*, the temperature of the magnesium oxide was measured by means of a Wanner pyrometer. Some of the data thus obtained are given in the upper part of the following table.

TABLE I.

Measured Energy Supplied.

No.	Amp.	Volts.	Watts.	Watts / cm.	Tempr. (abs.)	Watts / cm.	C. P.	C. P. / mm.²
I.	0.148	173	25.6	16.3	2,360°	1.79	14.8	3.25
II.	0.410	182	74.6	36.1	2,360	1.83	42.0	3.29
III.	0.846	175	148.0	52.9	2,360	1.75	86.8	3.22
IV.	0.810	103	83.5	59.6	1,800	1.90	47.0	3.36

In obtaining these data the writer had the coöperation and assistance of Professor Nernst and one of his assistants, but at that time some doubt arose as to the accuracy of the temperature determinations thus made, and they have not been published hitherto. The writer has since decided to make some independent temperature measurements following an entirely different method, the details of which are given below.

When Professor E. L. Nichols made his observations for the determination of the temperature of the acetylene flame,[1] it was the writer's privilege to assist in a small way. It seemed probable, therefore, that the same method used in those former measurements might be used to good advantage in determining the actual temperature of the incandescent glower when the latter was carrying a given constant load. Three specimens of the same platinum and platinum-rhodium wire used in the determinations just mentioned were therefore taken, pulled down to suitable size, and made into thermo-elements. After a 110-volt glower with its ballast had been mounted on a suitable frame and connected in series with an ad-

[1] Nichols, PHYS. REV., 10, p. 234, 1900.

justable rheostat, a current of 0.80 amperes — its rated normal load — was passed through the glower. The junction of the thermo-element was then moved slowly up to the incandescent glower. To the writer's surprise the junction could be brought in contact with the glower without melting or being otherwise visibly changed. This was true of the smallest junction used — the radius of which was 0.00360 cm. The only conclusion to be drawn was that the temperature of the incandescent glower was much lower than the early measurements indicated. The radii of the three junctions used were as follows: No. I., had a radius of 0.00592 cm.; No. II., of 0.00493 cm.; No. III., of 0.00360 cm.

The thermo-electromotive forces generated in these three thermo-elements were then measured on the potentiometer — the junction of the thermo-element being meantime in contact with the glower. From a curve, plotted from the values given by Kohlrausch,[1] the temperature corresponding to each electromotive force was then read and a curve was plotted with corresponding temperatures as ordinates and cross-sections of the wires as abscissæ. In order to eliminate conduction, this curve was extended back until it intersected the axis of ordinates. Thus one eliminated the conduction of the thermo-elements, and obtained at the intersection of the curve with the axis of ordinates, the value of the temperature that would be measured with a wire of zero cross-section. The values obtained from a series of measurements on a half dozen different glowers gave results varying from 1780° to 1800° absolute as is shown by the following table:

TABLE II.

Temperatures of Various Glowers as Measured with the Three Thermo-elements.

Glower.	Temperatures for Elements.			Exterpolated Value.
	No. I.	No. II.	No. III.	
I.	1,223°	1,407°	1,487°	1,505° C.
II.	1,220	1,430	1,500	1,515
III.	1,270	1,425	1,520	1,530
IV.	1,230	1,385	1,495	1,535
V.	1,145	1,320	1,460	1,510
VI.	1,150	1,330 (?)	1,480	1,515
			Mean value,	1,791 absolute.

[1] Kohlrausch, Praktische Physik, p. 157, 1901, 9te Aufl.

In some cases the glower was heated by direct current ; in others, by alternating current. Sometimes the glower was in the plane formed by the two wires of the thermo-junction ; sometimes the glower was at right angles to the plane including the two wires. In all cases the glower was horizontal. The mean of all these measurements gives a temperature of 1791° absolute.

After making these measurements, in order to make sure that the character of the wires of the thermo-elements had not been changed by contact with the hot oxides constituting the glower, the junctions were used to measure the temperature of various parts of the luminous cone of the Bunsen flame. Values concordant with those obtained by Waggoner[1] were obtained. Although under a microscope the wires did not present a perfectly smooth appearance like that of a newly drawn wire, yet the tests to which the junctions were subjected made it seem probable that the thermo-junctions used measured the true temperature of the Bunsen flame and of the glowers as accurately as one could expect, considering that there was more or less unavoidable change in the value of the current passing through the glower.

TABLE III. (*Computed.*)

Watts per Centimeter Length Required by Black Bodies for the Absolute Temperatures Indicated Below.

No.	Thickness.	1700°	1800°	1900°	2000°	2100°	2200°
		Watts per Centimeter.					
I.	0.0290 cm.	4.10	5.11	6.35	7.81	9.50	11.44
II.	0.0618 "	8.67	10.91	13.54	16.62	20.20	24.33
III.	0.0964 "	13.50	17.00	21.10	26.87	31.50	37.90
IV.	0.1000 "	14.10	17.60	22.00	27.00	32.70	

Some comparisons will now prove of interest. It will be instructive to compare the actual energy supplied to the glower when it is heated to a given temperature, with the energy required to produce the same temperature in a black body of the same dimensions as the Nernst glower. The computed data for the black body are given in Table III. For the absolute temperatures indicated in this table,

[1] Waggoner, Wied. Ann., **58**, 579, 1896.

the energy per centimeter length required by a black body of the same cross-section as the Nernst glower is given. In Table I. data showing the energy supplied to four different glowers are given. The first three are German glowers and the accompanying data were obtained by the method first mentioned above, using the Wanner Pyrometer and the iridium furnace to determine the temperature of the glower. The last case, glower No. IV., is one of the American glowers in which case the temperature of the glower was measured by means of the thermo-element. Glowers Nos. III. and IV. of this table are so similar that a comparison is possible. For example, the current strength in the two cases, the watts per centimeter length, the energy per sq. mm., and the candle power per sq. mm., are all of such a relative magnitude as to be comparable. In case of glower No. III., whose temperature was determined by the pyrometer, the temperature was found to be 2300° absolute. Judging from the candle power per sq. mm., glower No. IV. should be considerably hotter than glower No. III., but with the glower first mentioned the thermo-element showed a temperature of 1800° absolute. Evidently, therefore, the method used to measure the temperature of No. III. gave values much too high. In other words the laws of Wien and Paschen do not apply to the Nernst glower because it is not a black body, but on the contrary shows selective radiation when compared with the radiation from the latter. These laws cannot be used, therefore, with the constants now available for a black body, in order to determine the temperature of the Nernst glower.

If now we compute the energy lost by glowers Nos. I., II. and III., assuming for the time being that the black body law is followed and that the temperature obtained from measurements based on that law are correct, we find the watts lost per centimeter length to be relatively very small, as is shown by the first part of Table IV. and the percentage loss to be very small, ranging from 5 per cent. to 7 per cent. On the other hand, if we take the temperature obtained by the thermo-element method as the correct temperature of the glower, and then find the energy required to heat a black body of the same dimensions as the glower to the absolute temperature of 1800° we find a relative large loss, viz., 42 watts, or a percentage loss at 1800° absolute of 70.5 per cent.

The advantage from a commercial standpoint of rating the temperature of the Nernst glower above its actual value, is shown very clearly by these figures. From these considerations, it seems quite evident that the economic superiority of the glower over that of a black body is not so great as has been claimed for it. That it is far from being a black body, as has long been known, is also strikingly emphasized. That its true temperature has been placed too high is conclusive. Temperature measurements on the glower based on its radiating power or its photometric qualities, are alike apt to give values which are much too high.

TABLE IV.

Watts per Centimeter Length lost into the Air due to Conduction, Convection, etc.

No.	Absolute Temps.	Watts Lost.	Per Cent. Watts Lost.
I.	2,360°	1.01	6.2
II.	2,360	4.79	7.6
III.	2,360	2.61	5.2
IV.	1,800	42.00	70.5

PROCEEDINGS

OF THE

AMERICAN PHYSICAL SOCIETY.

MINUTES OF THE THIRTY-SECOND MEETING.

A REGULAR meeting of the Physical Society was held at Washington, D. C., on Friday, April 20, and Saturday, April 21, 1906. President Barus presided.

The Friday session was held at the Cosmos Club, and the Saturday sessions at the National Bureau of standards.

The program was as follows:

FRIDAY, APRIL 20.

1. Measurements of the Internal Temperatures of Common Materials. C. B. THWING.

2. On the Influence of Frequency upon the Self-inductance of Cylindrical Coils of Any Number of Layers. (Read by title.) J. G. COFFIN.

3. On the Geometric Mean Distance of Square Areas and their Use in the Calculation of Inductances. E. B. ROSA.

4. Cheltenham Magnetic Observatory Registration of Effects from Electric Cars over 12 Miles Distant. L. A. BAUER.

5. Mica Condensers as Standards of Capacity. E. B. ROSA and F. W. GROVER.

6. The Electrolytic Wave Detector. L. W. AUSTIN.

7. On the Determination of Melting Points by Radiation Methods. C. W. WAIDNER and G. K. BURGESS.

8. Talbot's Law as Applied to the Rotating Sectored Disk. E. P. HYDE.

9. A New Potentiometer. H. B. BROOKS.

SATURDAY, APRIL 21.

10. Direct Reading Methods for Resistance Comparisons. F. A. WOLFF.

11. The Velocity and Ratio e/m for the Primary and Secondary Rays of Radium. S. J. ALLEN.

12. New "Reststrahlen." A. H. PFUND.

13. Study of Polarization Phenomena in the Infra-red. A. H. PFUND.

14. Note on a New Form of Radiometer. W. W. COBLENTZ.

15. Fish eye Views. R. W. WOOD.

16. Interference Colors of Chlorate of Potash Laminæ. R. W. WOOD.

17. Fluorescence and Magnetic Rotation of Vapors. R. W. WOOD.

18. Resonance Radiation of Fluorescence of Sodium Vapor. R. W. WOOD.

SATURDAY AFTERNOON.

Professor H. A. Lorentz, of Leyden, addressed the Society on the subject of "Gibbs' Statistical Mechanics."

The regular program was then continued as follows:

19. The Ratio of the Electromagnetic and Electrostatic Units. E. B. ROSA and N. E. DORSEY.

20. Spectral Lines as Light Sources in Polariscopic Measurements. F. J. BATES.

21. Water of Crystallization and Water of Constitution. W. W. COBLENTZ.

22. Distribution of the Intensity of Radiation from Radioactive Substances. E. RUTHERFORD.

23. The Dispersion of Electric Waves. L. E. WOODMAN and H. W. WEBB.

24. Note on the Compound Interferometer. C. W. CHAMBERLAIN.

25. The Constancy of Platinum Thermo Elements and other Thermo-element Problems. W. P. WHITE.

26. Some Properties of Moving Coil Galvanometers. W. P. WHITE.

Adjourned.

ERNEST MERRITT,
Secretary.

NOTE ON A NEW FORM OF RADIOMETER.[1]

BY W. W. COBLENTZ.

THE chief objection to a radiometer having vanes of appreciable area is its slow period. This can be shortened by using a heavier fiber, which means a decrease in sensitiveness. This can be compensated for by increasing the efficiency of the vane. Now, in a radiometer the energy developed is at the surface of the vane, which by conduction transmits it to the surrounding medium. In the thermopile we use only the energy developed within the conducting wire.

[1] Abstract of a paper presented at the meeting of the Physical Society held April 20–21, 1906.

The present scheme is to superpose the radiometer effect upon the radiomiaometer effect, by placing the whole in a vacuum and making the Bi-Sb or Cu-Te thermojunction the vane of a radiometer. The junction is in the form of a ⊥, part of the long side being the vane. The loop of copper wire lies in the same plane and joins two of the free ends. The magnet is taken from a Weston ammeter. In other respects the whole is similar to the Boys radiomicrometer, with the exception that the suspended system is in a vacuum, which is an added advantage since, as shown by Kurlbaum, the sensitiveness is increased in a rarified atmosphere.

On account of numerous delays and pressure of other work, it has not been possible to give the instrument a thorough test for sensitiveness. It might be added, however, that the aim is not so much to develop an instrument which is more sensitive than a radiometer, but to construct a device that for a given sensitiveness has a shorter period than obtains in an ordinary radiometer. In an ordinary radiometer the suspension weighs about 10 to 12 mg. In the present case the weight is 20 mg. The half period is only 5 sec. at present. Selecting a finer fiber would make it more sensitive.

In conclusion I might add that I hesitate to give the data for sensitiveness of the present suspension (junction of Cu-Te), because the radiometer effect is only about fifteen per cent. of the radiomicrometer while it is well known that at all times the radiometer is the more sensitive instrument. By making the suspension of lighter material the radiometer effect will be increased. The present suspension is about three times as sensitive as the radiomicrometer described by Boys.

For measuring small electric currents, *e. g.*, from telephone, etc., we obviously need not have such a large vane. The heating coil is to be placed between the vane and what corresponds to the inner window of the radiometer as it appeared in its original form. It would seem that such an instrument ought to be more sensitive than the modification of the Boys' radiomicrometer which is now being exploited under a patent.

On the Determination of Melting Points by Radiation Methods.[1]

By C. W. Waidner and G. K. Burgess.

THE methods used are based on the monochromatic and on the total radiation from platinum at different temperatures. Minute specimens of the metals to be studied are placed on a platinum ribbon whose temperature is slowly raised by an electric current flowing through it;

[1] Abstract of a paper presented at the meeting of the Physical Society held April 20–21, 1906.

the melting is observed through a microscope, and the corresponding "black body" temperature of the platinum ribbon is observed with an optical or radiation pyrometer. From the known departure of platinum radiation from black body radiation, the true temperatures are obtained.

The platinum ribbon is mounted within an enclosure with mica window thus permitting determinations to be carried out in any desired atmospheres (air, H, N). The method is particularly applicable to the oxidizable elements, and also to the rare elements as only a few milligrams are required. Experiments with different size particles of metals of known melting points give the small correction for the temperature difference between strip and specimen undergoing melt.

The method has been applied to a study of the metals of the iron group and to palladium, and is applicable within the range 600° to 1650° C., and higher with iridium or graphite strips.

CHELTENHAM MAGNETIC OBSERVATORY REGISTRATION OF EFFECTS FROM ELECTRIC CARS OVER TWELVE MILES DISTANT.[1]

BY L. A. BAUER.

A CLOSE inspection of the magnetograms obtained during the past year at the United States Coast and Geodetic Survey Magnetic Observatory situated at Cheltenham, Maryland, employing the sensitive Eschenhagen-Edler variometers has disclosed the interesting fact that magnetic effects are being photographically registered daily which are to be ascribed to an electric car line 12 to 14 miles distant. This line proceeding from Washington to Mt. Vernon, Virginia, is a "single trolley" line with defective bonding of the rails.

The magnetic element principally affected, viz., the vertical intensity, exhibits during the period of the day (5 A. M. to about one and one half hours after midnight), when the cars are running, a number of short, more or less periodic, waves of fluctuations superimposed upon the normal curve. The average deflection to be ascribed to the electric car effect is about $\frac{1}{75000}$ to $\frac{1}{150000}$ part of the vertical intensity.

The effects are being further investigated; a fuller publication will be found in the March issue of the journal "Terrestrial Magnetism and Atmospheric Electricity."

Up to this time it had been generally supposed that no electric car effects could be detected beyond five miles.

[1] Abstract of a paper presented at the meeting of the Physical Society held April 20–21, 1906.

A New Potentiometer.[1]

By H. B. Brooks.

MEASUREMENTS of electromotive force and current are made with two general classes of instruments. Those of the first class may be called deflection instruments, those of the second, balance instruments. Most portable voltmeters and ammeters belong to the first class, while the potentiometer is the best example of the second class. Deflection instruments are less accurate, less permanent in calibration and more affected by external disturbing forces than balance instruments; on the other hand deflection instruments are less expensive and more readily applied, and readings may be taken more rapidly than with balance instruments. The latter are preferred for precision work in the laboratory; the former for approximate work in the laboratory and for commercial work. The merits of the potentiometer method for precision work are well known.

A middle class of work calls for an accuracy better than that of deflection instruments, but not so great as that of the precision potentiometer. It also requires permanency of calibration, independence of external disturbing forces and as much as possible of the convenience and speed of working of the deflection instrument. The work to be done by such an instrument includes the calibration of deflection instruments in the factory and testing room, the checking of ammeters and voltmeters in the central station, including switchboard instruments in position, and photometric work.

To meet this need larger deflection instruments have been supplied, and also portable potentiometers. The former may be read quite closely, on account of the longer needle; they are, however, subject to all the sources of error peculiar to deflection instruments. The portable potentiometer has not fully met the need, one reason being that measurements cannot be made unless the current or voltage to be measured is quite steady, a condition not found on commercial circuits.

To meet the need above mentioned a new form of potentiometer has been devised, which measures the bulk (say from 95 to 99 per cent.) of the quantity to be measured by the potentiometer principle, the remainder being measured by deflection. Thus the sources of error peculiar to the latter affect only a small portion of the result, while the operation of the instrument is much simplified. If the current or voltage is fluctuating, the instantaneous values may be read, it being unnecessary to change the dial unless the fluctuations are very great.

The instrument is a one dial potentiometer with a calibrated galvanometer, the circuits being so arranged that the sensibility is constant, re-

[1] Abstract of a paper presented at the meeting of the Physical Society held April 20–21, 1906.

gardless of the setting of the dial. The general expression for the galvanometer current in an unbalanced potentiometer has been derived and used as a guide in planning the circuits.

An instrument for voltage measurements on this principle has been constructed and used in the work of the Bureau of Standards. It has been found very accurate and much more convenient to use than a potentiometer of standard form. A second instrument will be constructed, in which more than one range will be provided for.

SELECTIVE REFLECTION IN THE INFRA-RED.[1]

BY A. H. PFUND.

TO begin with it is shown that the character of the selective reflection of a substance is not affected by a change of state, so long as the molecule as a whole remains unaffected. Then the curves of selective reflection from liquids are discussed — especially of sulphuric acid. These curves change markedly with changes in the concentration of the acid. The effect is attributed to the formation of new ions. Finally, it is shown that the mechanism giving rise to certain marked bands of selective reflection in the infra-red is in all probability localized in that portion of the molecule which in solution becomes the negative ion. All of the results thus far obtained (involving work on sulphates and nitrates) fully bear out the above conclusion.

POLARIZATION IN THE INFRA-RED.[1]

BY A. H. PFUND.

THE first part of the paper is taken up with a discussion as to the suitability of certain substances to act as polarizers in the infra-red. A new form of polarizer and analyzer is developed (involving the use of amorphous selenium), which has very decided advantages over existing forms. With these new instruments it is shown that Iceland spar in its region of metallic reflection transforms plane into elliptically polarized light by reflection.

[1] Abstract of a paper presented at the meeting of the Physical Society held April 20–21, 1906.

Spectral Lines as Light Sources in Polariscopic[1] Measurements.

By Frederick Bates.

RECENT progress in polariscopic work necessitates careful consideration of the character and behavior of the light sources used. Unless the source can be accurately defined and its constancy depended upon it is obviously impossible to compare the polariscopic measurements of different observers.

Let two spectral lines with unequal intensities be considered as a source of light for a half shade polariscope. It is found from a theoretical development that a rotation is measured which differs from the rotation that would have been obtained, had the lines been of equal intensity, by an angle

$$\delta = \pm \tfrac{1}{2} \frac{K - 1}{K + 1} (a_1 - a_2), \qquad (1)$$

where K is the ratio of the intensities and $(a_1 - a_2)$ is a function of the rotation dispersion.

By means of (1) we can calculate the optical center of gravity of the sodium lines and the errors in measuring rotations with these lines as the source of light.

The use of the line 546.1 $\mu\mu$ obtained from incandescent mercury vapor is advocated as the international standard source for all polariscopic measurements. In order to make possible the use of this source where the rotation value for quartz is desired in terms of the sodium lines a determination was made of the temperature coefficient and also the ratio of the rotation for the proposed source and the sodium lines.

We have thus the formula

$$a_t = a_0(1 + 0.000144t),$$

giving the rotation for quartz at any temperature between 4° C. and 50° C. for the line 546.1 $\mu\mu$. To give the rotation in terms of the sodium lines we have

$$\frac{\sigma_\lambda = 546.1}{\sigma_\lambda = 589.25} = 1.175166 \pm 0.000012.$$

[1] Abstract of a paper presented at the meeting of the Physical Society held April 20–21, 1906.

THE ELECTROLYTIC WAVE DETECTOR.[1]

BY L. W. AUSTIN.

THE electrolytic wave detector first described by Fessenden and later independently by Schlomilch consists essentially of a cell having as one electrode a point of fine platinum wire and containing an electrolyte the decomposition products of which are gaseous. When an E.M.F. is applied to such a cell powerful polarization ensues so that practically no current passes unless the E.M.F. exceeds a certain value. When electrical oscillations pass through the cell this resistance is for the time decreased but returns to its former value as soon as the waves cease.

This work was undertaken with the purpose of gaining some quantitative data regarding the detector and with the hope of settling some of the disputed points regarding its action. Experiments were made with the cell excited by alternating currents of low frequency and also by true electrical waves supplied for the most part from a station seven miles away. The action in the two cases seems to be in general the same.

The following are the principal results:

When the polarization is complete enough so that a sensitive galvanometer can be used, a few thousandths volts alternating E.M.F. can be detected.

The decrease in the resistance of the cell is approximately proportional to the square of the applied alternating E.M.F.

With increasing polarizing E.M.F. the sensitiveness increases to a maximum after which it remains constant or decreases.

Under favorable conditions the cell is found to be about equally sensitive with positive (oxygen) or negative (hydrogen) polarization on the point thus supporting the results of Fessenden and Rothmund and Lessing in opposition to those of DeForrest and Schlomilch. At times however the action with negative polarization is irregular, the resistance occasionally increasing instead of decreasing.

The resistance of the cell is very variable depending on the polarizing E.M.F. When the polarizing E.M.F. is low it may be 50,000 ohms or more while at the point where the polarization is beginning to break down it is sometimes less than 1,000 ohms. In the case of rapid oscillations the effective resistance is modified by the fact that the cell acts as a condenser.

For slow alternations the cell is equally sensitive whether the small electrode is minute or of considerable size. For oscillations of the period usually used in wireless telegraphy the area should not exceed 0.0003 mm. This difference in action is probably due to the capacity effect of the point.

[1] Abstract of a paper presented at the meeting of the Physical Society held April 20–21, 1906.

In order to test the hypothesis that heat is a prominent factor in breaking down the polarization resistance at the small electrode, this electrode was made in the form of a loop of wire through which an alternating heating current could be passed. It is found that the heating of the electrode produces a marked diminution in the resistance of the cell, which indicates that heat is at least one of the factors in the phenomenon.

On the Influence of Frequency Upon the Self-Inductance of Cylindrical Coils of any Number of Layers.[1]

By J. G. Coffin.

CALCULATIONS on a marble standard of self-inductance, constructed for the Bureau of Standards, showed that a change in the self-inductance with the frequency, of over 0.25 per cent., was possible.

In accurate work, this is a very large variation and it is necessary to derive a method for assigning the correction to be applied to any given coil at any given frequency.

Such a method is given in this paper, which is an extension of one for the corrections to a coil of a single layer, shortly to be published in the Bulletin of the Bureau of Standards.

Starting from Maxwell's equations, a differential equation is derived for the variation in the magnetic field as a function of the distance from the central axis of the coil, with any frequency.

The solutions of this equation are the Bessels functions of the zeroth order. Following A. Sommerfeld, these solutions are replaced by approximation formulæ, thus reducing the problem to one in simple functions alone.

An equation is then derived which gives the law according to which the variable part of the self-inductance of a coil of m-layers changes with the frequency.

Curves are drawn which render the calculations for any given coil very easy. Approximation formulæ for the case of low and high frequencies are also derived.

This paper will appear in a future number of the Physical Review.

[1] Abstract of a paper presented at the meeting of the Physical Society held April 20–21, 1906.

ON THE GEOMETRIC MEAN DISTANCES OF SQUARE AREAS, AND THEIR USE IN THE CALCULATION OF SELF AND MUTUAL INDUCTANCES.[1]

BY EDWARD B. ROSA.

MAXWELL gave the value of the geometric mean distance of two adjacent squares (*Trans. Royal Soc. Edinburgh*, 1871) as .99401 times the distance between their centers, and the geometric mean distance of two squares corner to corner as 1.0011 times the distance between their centers. From this he calculated the correction to be applied to the self-inductance of a coil of round wire of rectangular section to make allowance for the difference in the mutual induction of round wires on one another from the mutual induction of square wires. This correction is $-4\pi na \times .01971$ cm. (*Elec. and Mag.*, II., Par. 693). Stefan stated (*Wied. Am.*, 1884) that Maxwell's value was wrong, and gave the correction as $+4\pi na \times .01688$ but did not show how he got this value or wherein Maxwell's figure was wrong.

I have worked out the geometric mean distances of neighboring squares and find Maxwell's values wrong. For adjacent squares the figure is 1.00655 instead of .99401, and for squares corner to corner it is .997701 instead of 1.0011. The correction ΔM is therefore positive instead of negative as given by Maxwell, and its numerical value is never as great as that given by Maxwell. It is, however, not a constant (as stated by Stefan) but varies with the number of turns of wire in the coil and the shape of the cross section.

It is .01075 (multiplied by $4\pi na$) for a coil of four turns, 2×2, .01515 for 16 turns, 4×4, and has a limiting value of .01806 for a large number of turns.

Values of the geometric mean distances are deduced for 20 different squares situated in one quadrant from a given square. These are also of value in calculating the mutual inductances of parallel coils near each other.

MICA CONDENSERS AS STANDARDS OF CAPACITY.[1]

BY E. B. ROSA AND F. W. GROVER.

THE use of mica condensers as standards of capacity is justified by the most careful examination of their behavior. The capacity is not, however, perfectly constant, and in order to know the capacity at any given time it is necessary to know certain characteristic constants.

[1] Abstract of a paper presented at the meeting of the Physical Society held April 20–21, 1906.

That is, in addition to the capacity accurately determined under standard conditions we should know :

1. The temperature coefficient of the condenser. The coefficient is usually constant for a limited range of temperature, but it begins to increase rapidly at 25° to 30° C. in some condensers. It is therefore necessary to investigate the temperature variation carefully when the condenser is to be used at different temperatures.

2. Variation with time of charge and discharge, or frequency of current if subject to periodic electromotive force. As condensers are used in a variety of ways, it is necessary to know how the capacity varies with the method and rapidity of charge and discharge.

3. Variation with the potential used, that is, with the electric stress on the dielectric. The change of capacity with the potential employed is usually inappreciable, but is sometimes considerable.

4. The power factor of the condenser is an indicator of its quality. The best condensers have extremely small (but measurable) power factors ; yet some condensers made for standards show quite large power factors. The power factor depends both on leakage and absorption. The latter must be small when the power factor is small.

Results of measurements of these various quantities for several condensers will be given; as well as some of the methods employed in the measurements.

The Ratio of the Electromagnetic and Electrostatic Units.[1]

By E. B. Rosa and N. E. Dorsey.

ALTHOUGH this ratio has been determined by various investigators, their results do not give its value to within one part in a thousand, as there are considerable differences in the values obtained. We have been carrying out a series of investigations for nearly two years in order to determine its value at least to 1 part in 5,000, and hope to fix its value to within 1 in 10,000.

In order to give as great weight as possible to our result, we have employed more than one apparatus and more than one method, and have varied the working conditions in many ways. The following are some of the main features of the work :

1. We have used the condenser method, getting the capacity of condensers by calculation from their dimensions and their electromagnetic capacity by rapidly charging and discharging them. This method is undoubtedly superior to any other for accurate work, being probably the only method capable of high accuracy.

[1] Abstract of a paper presented at the meeting of the Physical Society held April 20–21, 1906.

2. We have used three forms of condensers, spherical, cylindrical and plane. The spherical has two inner balls, giving two different capacities; the plane has one plate movable, giving a variety of capacities. The spherical requires no guard ring, is the simplest form, but requires careful determination of the capacity of the charging wire which protrudes through a hole in the outer shell. The plane and cylindrical condensers have guard rings, but are simpler with respect to the capacity of the charging wire. Using such a variety of forms and sizes of condensers gives a thorough test as to any errors that might remain as constant errors in a determination with a single instrument.

3. The electrostatic capacities have been determined with the greatest care, using standards of length and mass in so doing that have been calibrated by reference to the standards of the Bureau of Standards.

4. The electromagnetic capacities have been determined by two separate methods, (1) the Maxwell bridge method and (2) a differential galvanometer method. In the latter case the charges were sometimes measured and at other times the discharges. No differences could be detected between these, and the bridge and differential methods have also agreed.

5. The resistances used have been in oil, they have been carefully standardized, they have been used at various temperatures, different boxes have been employed for a given purpose and every precaution taken to discover sources of error and to eliminate accidental errors.

The apparatus employed in this work will be exhibited and the results so far obtained will be given. The mean value of all the measurements is about 2.9961×10^{10}.

WATER OF CRYSTALLIZATION AND WATER OF CONSTITUTION.

BY W. W. COBLENTZ.

MANY chemical compounds contain both oxygen and hydrogen, which, on applying heat, pass off in the form of water. The manner in which the water exists in minerals of this kind is not understood. By some it is considered a part of the chemical molecule; by others it is thought that the molecules of water exist in their entirety among the other molecules which constitute the compound. From the circumstance that many of these compounds are crystalline, the water is said to be present as "*water of crystallization.*" It is a characteristic of water of crystallization that it is expelled at a temperature far below red heat and frequently below 100° C.

On the other hand, the water which is given off only at a red, or even a white heat, can scarcely be present in the compound in the same man-

[1] Abstract of a paper presented at the meeting of the Physical Society held April 20–21, 1906.

ner as water of crystallization and is distinguished as "water of constitution." In this case, the water is not supposed to exist as such in the mineral, but to result from the union of oxygen or hydrogen, or from the hydroxyl groups contained in the compounds. The whole question is in an unsettled state, while the data bearing upon it is almost *nil*.

In a preliminary paper[1] bearing upon the subject, the writer described the infra-red absorption spectra of two minerals, selenite, $CaSO_4 + 2H_2O$, and brucite, $Mg(OH)_2$ in which the atoms of oxygen and hydrogen are thought to be combined in a different manner.

It was the application of the results of the previous work in which it was abundantly proven that certain groups of atoms have characteristic absorption bands. Hence, if the oxygen and hydrogen, which enter into the composition of certain minerals, are bonded as they are in a molecule of water, then one would expect to find the absorption spectra of such minerals to be the composite of the bands of ordinary water and of the bands due to the other constituents. In the previous paper, selenite and brucite were selected as characteristic examples. They confirmed the theory in a broad sense, but two minor details needed further inquiry. First, the water band at 4.75 μ was too deep in selenite for the thickness of the plate examined, and in addition, it was shifted to 4.65 μ. This would suggest that the band is complex. From its great depth and from the behavior of the sulphur compounds in this region, it was surmised that the band might be due to SO_4 radicle.

In the second place, the OH radicles in brucite contradicted other work in which it was found that the hydroxyl group causes an absorption band at 3 μ. For these and other reasons it was deemed worth while to give the subject a thorough investigation.

For reasons too extensive to be discussed here, the minerals were examined in unpolarized light. The infra-red absorption spectra were examined by means of a large mirror spectrometer, a rock salt prism and a Nichols radiometer. The chief difficulty encountered was in obtaining suitable minerals, which were then ground to a thickness of about 0.1 mm. Over a hundred minerals have been examined, the majority having oxygen or hydrogen. As yet, the results have not been thoroughly worked out.

The exceptions to the rule that minerals containing water of crystallization should show water bands are but few, and belong to the group which is in doubt by mineralogists. At least thirty minerals containing water of crystallization were examined. In the same manner, the exception to the rule that minerals containing water of constitution should *not* show water bands is confined to cane sugar, which in all forms, from amorphous to crystals of rock candy, shows water bands. From com-

[1] PHYSICAL REVIEW, 20, p. 252, 1905.

parison with dextrose, maltose and lactose, it would contain one molecule of water crystallization.

The list of sulphates examined is extensive and gives concordant results in showing a band at 4.55 μ due to the SO_4 radicle.

In the silicates, as well as in many other compounds, the general absorption increases beyond 5 μ. The maxima of the metallic reflection bands and the same determined from the transmission curves do not always coincide.

A series of hydroxides show a band at 3 μ. Brucite is *not* an exception to the rule for hydroxyl groups. Using a larger dispersion and a very much thinner film, the large band at 2.6 μ is now found to be complex with maxima at 2.5, 2.7 and 3 μ.

In quartz the first band is found at 2.9 μ. This is followed by pairs of bands at 5.0–5.3, 5.95–6.22, 8.49–9.03 and a wide band at 20.75 μ.

In the silicates studied the first band is at 2.85 or 2.91 μ, while the following ones may be at 5.6 μ and at 5.95 or 6.22 μ (sometimes both are present). Beyond this point the opacity is too great to extend observations.

The micas are known to have pairs of "reststrahlen" bands at 8.32–9.38 and 18.4–21.25; the latter being represented in quartz by the band at 20.75 μ.

On first consideration these bands seem harmonic. If we take the difference of the reciprocals of the wave-lengths of the pairs at 2.85–2.91, 5.95–6.22, 8.49–9.03 and 18.4–21.25 μ, we find that the value, in whole numbers, is from 70 to 72 which would indicate a spectral series of doublets. While not much reliance can be placed upon such results considering the present state of our knowledge, the relations indicated are very suggestive. In view of this fact, with the accumulation of minerals at hand, it is hoped to extend the work by means of metallic reflection using a bolometer and a wire grating. The most important minerals have been examined to 12 μ by means of (metallic) reflection and it will be sufficient to add that the sulphates have a series of reflection bands at 8.1 to 9.1 μ beyond which they again become transparent. The band at 9.1 μ is harmonic with the absorption band at 4.55 μ. The reflection band at 8.7 μ which is marked in the sulphates examined, viz., Ca, Mg, Ba, Sr and Na, is the strongest absorption band in SO_2. As a whole it appears that the SO_4 radicle can be added to the list[1]: viz., CH_3, NH_2, C_6H_6, NO_2, OH and NCS, which have characteristic absorption bands in the infra-red. The silicon radicle is still in doubt.

BUREAU OF STANDARDS,
WASHINGTON, D. C.

[1] PHYS. REV., 20, p. 362. 1905.

Some Properties of the Moving Coil Galvanometer.[1]

By Walter P. White.

BY combining equations (1), (5), (13) and (16), of the author's article on sensitive moving coil galvanometers,[2] we obtain the equation

$$H = A\sqrt{\frac{R}{R'T}}, \qquad (1)$$

where R is the critical resistance, R' the resistance of the coil, T the full undamped period, and H the mean effective field strength in c.g.s. units. A is constant on the assumption used in obtaining the original equations — namely, that all inert material in the coil can be neglected. It is, however, constant in any case for the same coil, it varies within rather narrow limits (from 600 to 800) for such coils as are ordinarily used, and can be estimated within ten per cent. from the dimensions and appearance of the coil. Therefore,

1. This equation gives a simple method for measuring the effective field strength of the magnet of a galvanometer without removing the coil from the case, and without knowing the size of wire or the number of turns in the coil.

2. Our ability to obtain short periods depends on the magnet and the internal and external resistance, regardless of the sensibility or the mass of the coil.

3. In applying the above equation to a copper damping frame, $R/R' = 1$ and A, on account of the absence of insulating material, is lower, varying from 425 to 500. This case gives the lowest value of $A\sqrt{R/R'}$ obtainable with copper. Hence the shortest possible period for any kind of a copper coil whatever is given by the equation

$$H = \frac{425}{\sqrt{T}}. \qquad (2)$$

For aluminum, $H = 236/\sqrt{T}$.

4. For a coil whose damping is partly due to a copper or aluminum frame, the minimum period lies between the values proper to the frame and to the coil; but obviously, it will always be greater than that given by equation (2). The equation for this case is

$$H = A\sqrt{\frac{R}{R'T}}\sqrt{\frac{D + d\frac{R'a^2}{RA^2}}{D + d}},$$

[1] "Sensitive Moving Coil Galvanometers," Physical Review, 19, 305. 1904.

[2] Abstract of a paper presented at the meeting of the Physical Society held April 20–21, 1906.

parison with dextrose, maltose and lactose, it would contain one molecule of water crystallization.

The list of sulphates examined is extensive and gives concordant results in showing a band at 4.55 μ due to the SO_4 radicle.

In the silicates, as well as in many other compounds, the general absorption increases beyond 5 μ. The maxima of the metallic reflection bands and the same determined from the transmission curves do not always coincide.

A series of hydroxides show a band at 3 μ. Brucite is *not* an exception to the rule for hydroxyl groups. Using a larger dispersion and a very much thinner film, the large band at 2.6 μ is now found to be complex with maxima at 2.5, 2.7 and 3 μ.

In quartz the first band is found at 2.9 μ. This is followed by pairs of bands at 5.0–5.3, 5.95–6.22, 8.49–9.03 and a wide band at 20.75 μ.

In the silicates studied the first band is at 2.85 or 2.91 μ, while the following ones may be at 5.6 μ and at 5.95 or 6.22 μ (sometimes both are present). Beyond this point the opacity is too great to extend observations.

The micas are known to have pairs of "reststrahlen" bands at 8.32–9.38 and 18.4–21.25; the latter being represented in quartz by the band at 20.75 μ.

On first consideration these bands seem harmonic. If we take the difference of the reciprocals of the wave-lengths of the pairs at 2.85–2.91, 5.95–6.22, 8.49–9.03 and 18.4–21.25 μ, we find that the value, in whole numbers, is from 70 to 72 which would indicate a spectral series of doublets. While not much reliance can be placed upon such results considering the present state of our knowledge, the relations indicated are very suggestive. In view of this fact, with the accumulation of minerals at hand, it is hoped to extend the work by means of metallic reflection using a bolometer and a wire grating. The most important minerals have been examined to 12 μ by means of (metallic) reflection and it will be sufficient to add that the sulphates have a series of reflection bands at 8.1 to 9.1 μ beyond which they again become transparent. The band at 9.1 μ is harmonic with the absorption band at 4.55 μ. The reflection band at 8.7 μ which is marked in the sulphates examined, viz., Ca, Mg, Ba, Sr and Na, is the strongest absorption band in SO_2. As a whole it appears that the SO_4 radicle can be added to the list[1]: viz., CH_3, NH_2, C_6H_6, NO_2, OH and NCS, which have characteristic absorption bands in the infra-red. The silicon radicle is still in doubt.

BUREAU OF STANDARDS,
WASHINGTON, D. C.

[1] PHYS. REV., 20, p. 362. 1905.

Some Properties of the Moving Coil Galvanometer.[1]

By Walter P. White.

BY combining equations (1), (5), (13) and (16), of the author's article on sensitive moving coil galvanometers,[2] we obtain the equation

$$H = A\sqrt{\frac{R}{R'T}}, \qquad (1)$$

where R is the critical resistance, R' the resistance of the coil, T the full undamped period, and H the mean effective field strength in c.g.s. units. A is constant on the assumption used in obtaining the original equations — namely, that all inert material in the coil can be neglected. It is, however, constant in any case for the same coil, it varies within rather narrow limits (from 600 to 800) for such coils as are ordinarily used, and can be estimated within ten per cent. from the dimensions and appearance of the coil. Therefore,

1. This equation gives a simple method for measuring the effective field strength of the magnet of a galvanometer without removing the coil from the case, and without knowing the size of wire or the number of turns in the coil.

2. Our ability to obtain short periods depends on the magnet and the internal and external resistance, regardless of the sensibility or the mass of the coil.

3. In applying the above equation to a copper damping frame, $R/R' = 1$ and A, on account of the absence of insulating material, is lower, varying from 425 to 500. This case gives the lowest value of $A\sqrt{R/R'}$ obtainable with copper. Hence the shortest possible period for any kind of a copper coil whatever is given by the equation

$$H = \frac{425}{\sqrt{T}}. \qquad (2)$$

For aluminum, $H = 236/\sqrt{T}$.

4. For a coil whose damping is partly due to a copper or aluminum frame, the minimum period lies between the values proper to the frame and to the coil; but obviously, it will always be greater than that given by equation (2). The equation for this case is

$$H = A\sqrt{\frac{R}{R'T}}\sqrt{\frac{D + d\frac{R'a^2}{RA^2}}{D + d}},$$

[1] "Sensitive Moving Coil Galvanometers," Physical Review, 19, 305. 1904.

[2] Abstract of a paper presented at the meeting of the Physical Society held April 20–21, 1906.

where D is the damping coefficient of the coil, d that of the frame, and a the value of A for the damping frame.

The detrimental magnetic effect is proportional to the magnetic attraction divided by the controlling force; that is, to H^2K/Q, if the shape and manner of construction of the coil do not vary. By the use of equation (1), it can then be shown to be proportional to TR/R'; that is, zero shifts, etc., are in general less troublesome at short periods.

The Constancy of Platinum Thermoelements, and Other Thermoelement Problems.[1]

By Walter P. White.

I.

IT has frequently been observed that thermoelements of metals of the platinum group deteriorate when exposed at 1200° or even less in a reducing atmosphere. The trouble has been variously attributed to reduced silicon or absorbed gases, but appears not to have been thoroughly investigated. It is usually removed by sufficient heating of the wires in air. At this laboratory, much trouble has been experienced from contamination of a character totally different and apparently hitherto unrecognized. It occurs at higher temperatures (1000 to 1600°), in an oxidizing atmosphere, and is much more serious.

The total thermoelectromotive force in any circuit equals $\int T dH$, where T is the temperature above that of the cold junction, and H is the thermoelectric height. In a thermoelement which is not homogeneous, therefore, the reading depends on a large number of different temperatures, namely, those at every point at which there is a change in the character of the wire. The reading of the contaminated elements, therefore, varied irregularly, according to the accidental condition of the furnace in which they were placed. It was found possible, however, to work with such elements by comparing them frequently with standards, taking great pains to make the comparison under conditions of temperature distribution in the furnace as nearly as possible the same as those prevailing when the elements were used to read temperatures. The standards were in use only a few minutes each day, and therefore deteriorated with relative slowness. At 1400° results obtained by this method generally agree within one third of a degree.

An investigation into the cause of the trouble, with a view to its prevention, began with the physical study of the contaminated wire, that is, of its thermoelectric properties.

[1] Abstract of a paper presented at the meeting of the Physical Society held April 20–21, 1906.

Several different forms of apparatus were tried. Their general principle is the following: The wire to be tested was in contact at two points, *A* and *B*, one or two centimeters apart, with two lead wires of the same material which ran off to a cold junction. *A* was heated indirectly by means of steam, while *B* was kept cool. The wire between *A* and *B* thus formed part of a thermoelement; and its thermoelectric height compared to the lead wires, and therefore the amount of its deterioration, could be easily found. Since all the wires were of the same material, the method was a differential one, and slight inequalities of temperature in the circuit, as well as small changes in the difference of temperature beween *A* and *B*, did little harm. In the apparatus that was found best for general work, *A* and *B* were over and insulated from plates of copper. For one or two special investigations a sharper temperature gradient was obtained by using two baths of kerosene, each containing a stirrer, and separated by a thin wooden partition through which the wire passed.

With the testing apparatus it was possible to get not only more definite results than could be obtained by the observation of thermoelements in furnaces, but to work on pieces of wire 2 or 3 cm. long, which could easily and at slight expense be subjected to various conditions. The investigation then undertaken yielded the following results:

1. The contamination of the platinum wire causing the change in electromotive force probably represents in the worst cases two or three per cent. of added impurity.

2. The platinum-rhodium wires are altered in electromotive force about one fourth as much as the platinum, which probably indicates an equal percentage of added impurity.

3. The contamination is first noticed at about 1000° and increases with the temperature. (Of course it also increases with the time.)

4. Only a little of the contaminated material is removed by glowing, that is, heating the wires nearly to their melting points by an electric current.

5. Wires heated in carbon monoxide and illuminating gas under a wide variety of conditions showed no contamination at high temperatures, 1200° and above.

6. Wires heated to 1500° for an hour in a glazed porcelain tube showed no contamination; no contaminating substance came through the furnace, and the porcelain gave out none. There is therefore probably no danger of contamination from silicates in an oxidizing atmosphere.

7. A platinum wire in a porcelain tube with a wire containing ten per cent. of iridium showed about as much contamination as when used in the furnace. Iridium from the coils of our furnace, which contain ten per cent. of it, is therefore probably the main cause of the trouble we have experienced.

8. Chemical analysis showed iridium in substantially the expected amount.

9. A few milligrams of iron wire inserted in the tube caused contamination. The wire probably exhausted the oxygen in the tube when first put in.

10. Ferric oxide at the same temperature (1500°) produced no contamination.

11. The wires were not contaminated in front of a blast lamp, but they were in the exhaust from a Fletcher furnace. Iron in some form was found to be present in the gases from this furnace, which also probably gave at times a reducing atmosphere.

12. When a tube of commercial platinum was used to shield the test wire from the furnace atmosphere, the wire was still contaminated. When the tube itself was tested thermoelectrically, it was found to contain at least three or four per cent. of impurity. As much of this was probably iridium, its presence is believed to be the cause of the contamination obtained with this tube. Thermoelectric tests of other samples of commercial platinum show from one half of one per cent. of iridium upward. Proximity to commercial platinum is therefore a source of danger to thermoelements at high temperatures.

13. A Heraeus thermoelement from the Corning Glass Works, which had been in continuous use for five months at 1400° in gas furnaces, showed one or two per cent. contamination of the platinum wire; far less in proportion to the time than was shown by our elements. But a striking difference was found in the condition of the rhodium-alloyed wire, which was not contaminated at all. A chemical test is now in progress to see whether the contamination in this case was due to rhodium from the rhodium wire.

14. Two attempts to check the contamination of wires by the use of a nitrogen atmosphere have failed. Further work, however, will be done in this direction.

CONCLUSION.

The proximity of platinum containing iridium, etc.; that is, practically all commercial platinum, will cause deterioration of platinum thermoelements when exposed in an oxidizing atmosphere above 1000°. There is apparently no other source of danger in an oxidizing atmosphere.

II.

Ordinary wires of constantan, German silver, etc., show inhomogeneities which greatly detract from their value in thermoelectric work. By using a thermopile instead of a thermoelement, the total electromotive force was increased and at the same time it was hoped that the inhomo-

geneities would tend to neutralize each other's effect. Experience seemed to show that it was better to first test the condition of the wire rather than rely on accidental corrections. A wire tester adapted to insulated wires several meters in length was made of a steam-jacketed glass tube. The wire was gradually drawn out of this tube, so that the thermoelectric height of the portion which was at the opening at any time was compared directly with another immovable portion. The result showed for No. 36 Advance wire a rise and fall of thermoelectric height with a fairly constant period of 60 cm., averaging about .25 per cent. of the electromotive height against copper, or over ten times the height of the short period variations found by Professor Hall.[1]

GEOPHYSICAL LABORATORY, CARNEGIE INSTITUTION,
WASHINGTON, D. C., April, 24, 1906.

THE VELOCITY, AND RATIO e/m, FOR THE PRIMARY AND SECONDARY β-RAYS OF RADIUM.[2]

BY S. J. ALLEN.

THE work of Kaufmann has shown that the primary β-rays are composed of negatively charged particles travelling with velocities nearly equal to that of light, and that further, as the velocity of light is approached the apparent mass of the electron increases rapidly. In trying to repeat these results, using, instead of the photographic method of Kaufmann, the well-known ionization one, the author experienced at first great difficulty in getting any true deflection of the β-rays. By further investigation however this difficulty was shown to be due to the presence of secondary and tertiary rays, which to a great extent masked the action of the primary β-rays.

An investigation into the nature of these secondary and tertiary rays, more especially absorption tests, and their behavior in a magnetic field, brought forth the following facts:

1. When the β-rays strike upon solid objects, there is produced at the surface of these, secondary rays, which differ both in quantity, and penetrating power with the nature and density of the object.

2. Nearly all of the secondary rays, whether from dielectrics or metals, are deflected in a magnetic field in the same direction as the primary β-rays would be.

[1] Proc. Am. Acad., 41, 543.

[2] Abstract of a paper presented at the Washington Meeting of the Physical Society, April 21, '06.

3. The penetrating power of secondary rays is greater for the substances of high density, but in any case it is not much less than the medium and slow velocity primary rays.

4. When the secondary rays in turn strike upon solid objects, there is produced a third type of rays similar in all respects to the secondary rays, but of slightly less penetrating power.

5. The amount of secondary rays produced by the γ-rays is small compared with that produced by the β-rays, but is of the same general nature. From these results an explanation of the difficulty experienced at first by the author can at once be obtained.

When a beam of β-rays, cut down to a supposed narrow width is allowed to fall upon the window of an electroscope of width the same as that of the incident beam, then besides this beam of β-rays there is also present a diffuse beam of secondary and tertiary rays, which as has just been shown are of the same general nature as the β-rays themselves, *i. e.*, deflectable in a magnetic or electrostatic field. Consequently the deflection of the β-rays would be very much confused by the accompanying deflection of the secondary and tertiary rays, so that an apparent total deflection of some 30 per cent. might mean more than complete deflection of the primary rays.

This difficulty was removed by the following method which proved successful.

The beam of β-rays was just prevented from entering the electroscope window by a suitable screen. Now it was found that, when the magnetic or electrostatic field was applied in such a direction as would bend the rays into the window, the ionization in the electroscope gradually increased to a maximum with increasing fields. When this maximum point had been reached for either the magnetic or electrostatic fields, the β-rays of least velocity had just been bent across the electroscope window. Knowing the strengths of the magnetic and electrostatic fields necessary to produce this maximum ionization, the velocity of the least penetrating ray could at once be calculated. By interposing in the path of the rays suitable layers of absorbing material, the velocity of the least penetrating ray which could just get through the absorbing layer could be ascertained. The effect of the secondary and tertiary rays was to change the amount of the increase of ionization but not the maximum point.

The experiments were performed in a high vacuum, the rays emerging from the vacuum vessel through a thin sheet of mica.

The velocity of the secondary rays was obtained in exactly the same manner, the radium being enclosed in a lead box which cut off all the primary rays and allowed only the secondary rays to pass out through a small opening. The complete results for both primary and secondary rays are given in the following table:

Primary β-Rays.

Absorbing Layer.	X (max.).	H (max.).	mv/e	V cm./sec.	e/m
0	—	—	1.57×10^{3}	2.20×10^{10}	1.40×10^{7}
6 sheets paper.	5.7×10^{11}	13.5	1.87	2.37	1.27
10 " "	6.1	14.3	1.98	2.40	1.21
14 " "	6.6	15.1	2.10	2.45	1.17
18 " "	7.2	16.2	2.25	2.49	1.10
22 " "	7.7	17.0	2.36	2.54	1.07
30 " "	8.3	17.9	2.49	2.60	1.04
1.5 mm. glass.	9.6	20.0	2.78	2.69	.96
.3 " copper.	11.0	22.2	3.09	2.77	.90
.4 " zinc.	14.0	27.2	3.79	2.88	.76
.8 " "	—	—	4.60	2.95	.64
1.2 " "	—	—	5.00	2.97	.59

Secondary Rays from Lead.

0	—	—	1.56×10^{3}	—	—
6 layers paper.	6.9×10^{11}	16.0	1.85	2.35×10^{10}	1.27×10^{7}
14 " "	7.5	17.0	1.97	2.40	1.21
22 " "	8.5	18.5	2.16	2.50	1.16
30 " "	9.6	20.2	2.36	2.58	1.09

Is will be seen at once from these tables that the limiting velocity of the rays for the same thickness of material is the same for both primary and secondary radiations. The values of the velocity, and ratio e/m, for the rays are very close to those found by Kauffman, and lend additional weight to the view that the mass of the election is entirely electrical in nature. The fact is also brought out in this investigation that the secondary rays are of the same nature as the primary β-rays, and travel at nearly the same velocity.

JOHNS HOPKINS UNIVERSITY,
BALTIMORE, MD.,
April 26, 1906.

INDEX TO VOLUME XXII.

A.

Adams, E. P., The Absorption of Alpha-Rays in Gases and Vapors, 111.

Allen, S. J., The Velocity and the Ratio *e/m* for the Primary and Secondary Rays of Radium, 375.

Alloys, Thermoelectric Heterogeneity in, *E. H. Hall, L. L. Campbell, S. B. Serviss*, 246.

Alpha-Ray Activity of Radioactive Minerals, *B. B. Boltwood*, 320.

Alpha-Rays, The Absorption of, in Gases and Vapors, *E. P. Adams*, 111.

Alpha-Rays from Radium, Some Properties of, *E. Rutherford*, 123.

Alpha-Rays from Radium, Magnetic and Electrical Deflection of, *E. Rutherford*, 122.

American Physical Society. See Physical Society.

Arcing, On the Conditions for Sparking at the Break of an Inductive Circuit, *J. C. Hubbard*, 129.

Areas, On the Geometric Mean Distances of Squares and their use in the Calculation of Self- and Mutual Inductances, *E. B. Rosa*, 366.

Austin, L. W., On the Emission of Negatively Charged Particles Produced by Canal Rays, 312.

The Electrolytic Wave Detector, 364.

B.

Ballistic Galvanometer, Damping of a, *A. W. Smith*, 250.

Ballistic Work, Adjustment of the d'Arsonval Galvanometer for, *F. Wenner*, 192.

Balance, Equal Arm, *H. V. Carpenter and Zella E. Bisbee*, 31.

Barnes, H. T., Differential Temperature Records in Meteorological Work, 112.

Temperature Records of Nocturnal Radiation, 250.

Barus, Carl, Condensation Nuclei, Presidential Address, 82.

Nucleation and Ionization of Carbon Dioxide and Coal Gas, 252.

Bates, Frederick, Spectral lines as Light Sources in Polariscopic Measurements, 363.

Bauer, L. A., Cheltenham Magnetic Observatory Registration of Effects from Electric Cars over Twelve Miles Distant, 360.

Benedict, Francis Gano, A Method of Calibrating Gas Meters, 294.

Bisbee, Zella E., Equal Arm Balance, 31.

Boltwood, B. B., On the Relative Proportion of the Total Alpha-Ray Activity of Radioactive Minerals due to the Separate Constituents, 320.

Boltzman, Ludwig, *Populäre Schriften*, 255.

Boyd, Jas. E., *Differential Equations. A Short Course for Engineering Students*, 62.

Briggs, Lyman J., On the Use of Centrifugal Force in Soil Investigations, 125.

An Electrically Controlled Thermostat Operable at Room Temperature, 126.

Brooks, H. B., A New Potentiometer, 361.

Buckingham, E., Methods of Soil Hygrometry, 248.

Bucherer, Dr. A. H., *Mathematische Einführung in die Electronentheorie*, 52.

Burgess, G. K., On the Determination of Melting Points by Radiation Method, 359.

C.

Cady, W. G., A Machine for Compounding Sine Curves, 249.
A Self-recording Magnetic Declinometer, 249.
Calibration of Gas Meters, A Method of, *F. G. Benedict*, 249.
Campbell, L. L., Thermoelectric Heterogeneity of Certain Alloys, 246.
Canal Rays, On an Emission of Negatively Charged Particles Produced by, *L. W. Austin*, 312.
Capacity of Mica Condensers, *Anthony Zeleny*, 65.
Carbon, The Optical Properties of, *Herbert A. Clark*, 247.
Carpenter, H. V., Equal Arm Balance, 31.
Cartmel, Wm. B., The Optical Properties of Very Thin Films, 115.
Centrifugal Force, On the Use of, in Soil Investigations, *Lyman J. Briggs*, 125.
Child, C. D., Conductivity of Vapor from the Mercury Arc, 221.
Chwolson, O. D., *Lehrbuch der Physic*, 60.
Clark, Herbert A., The Optical Properties of Carbon, 247.
Coblentz, Wm. W., Infra-red Emission Spectra, 1.
Note on a New Form of Radiometer, 358.
Water of Crystallization and Water of Constitution, 368.
Coffin, J. G., On the Effect of Frequency upon the Self-inductance of Cylindrical Coils of any Number of Layers, 365.
Collins, A. Frederick, *Wireless Telegraphy, Its History, Theory and Practice*, 63.
Color Photography, Improvements in the Diffraction Process of, *Herbert E. Ives*, 339.
Condensation Nuclei, *Carl Barus*, 82.
Condensers, Mica, as Standards of Capacity, *E. B. Rosa and F. W. Grover*, 366.
Condensers, The Capacity of Mica, *Anthony Zeleny*, 65.
Conduction, The Phenomena of Ionization, in Flame Gases and Vapors, *F. L. Tufts*, 193.
Conductivities Imparted to a Flame of Illuminating Gas by Vapors of Salts of the Alkali Metals, The Relative, *F. L. Tufts*, 113.
Conductivity of the Air Due to the Sulfate of Quinine, Fanny Cook Gates, 45.
Conductivity of the Vapor from the Mercury Arc, *C. D. Childs*, 221.
Cook, S. R., on the Velocity of Sound in Gases at Low Temperatures, and the Ratio of the Specific Heats, 115.
Crystallization, Water of, and Water of Constitution, *W. W. Coblentz*, 368.
Curves, A Machine for Compounding Sine, *W. C. Cady*, 249.

D.

Dadourian, H. M., The Radioactivity of Thorium, 251.
Damping of a Ballistic Galvanometer, *A. W. Smith*, 250.
D'Arsonval Galvanometer, Some Properties of the Moving Coil Galvanometer, *Walter P. White*, 371.
Davis, Harvey N., Longitudinal Vibrations Analogous to those of a Violin String, 121.
Decay of Phosphorescence in Sidot Blende, *E. L. Nichols and Ernest Merritt*, 279.
Declinometer, A Self Recording Magnetic, *W. G. Cady*, 249.
Deflection of Alpha-Rays from Radium, Magnetic and Electric, *E. Rutherford*, 122.
Depolarizer, Electrolytic Mercurous Sulfate as, for Standard Cells, *Geo. A. Hulett*, 47.
Dersau, B. (German Transl.), *Die moderne Theorie der Physikalischen Erscheinungen*, 255.
Differential Temperature Records in

Meteorological Work, *C. H. McLeod and H. T. Barnes*, 112.
Diffraction Process in Color Photography, Improvements in, *H. E. Ives*, 339.
Dorsey, N. E., The Ratio of the Electromagnetic and Electrostatic Units, 367.

E.

Electrodynamometer, A New Determination of the E.M.F. of Clarke and Cadmium Standard Cells by the Absolute Electrodynamometer, *K. E. Guthe*, 117.
Electrolytic Mercurous Sulfate as a Depolarizer for Standard Cells, *Geo. A. Hulett*, 47.
Electrolytic Wave Detector, *L. W. Austin*, 364.
Electromagnetic and Electrostatic Units, On the Ratio of the, *E. B. Rosa and N. E. Dorsey*, 367.
E.M.F. of Clarke and Cadmium Cells by Means of an Absolute Electrodynamometer, A New Determination of, *K. E. Guthe*, 117.
Emission of Negatively Charged Particles Produced by Canal Rays, *L. W. Austin*, 312.
Equal Arm Balance, *H. V. Carpenter and Zella E. Bisbee*, 31.
Ewell, A. W., Electrical Production of Ozone (Abstract), 111.
Same (Complete paper), 232.

F.

Films, The Optical Properties of Exceedingly Thin, *W. B. Cartmel*, 115.
Fitch, Philip, On the Measurement of the Index of Refraction by the Interferometer, 345.
Fite, Wm. B., *Differential Equations, A Short Course for Engineering Students*, James E. Boyd, 62.
Flame Gases and Vapors, The Phenomena of Ionization in, *F. L. Tufts*, 193.
Freezing of Pure Liquids and Solutions Under Different Kinds of Positive and Negative Pressures, *C. S. Hudson*, 257.
Frequency, On the Effect of, upon the Self-Inductance of Cylindrical Coils of any Number of Layers, *J. G. Coffin*, 365.
Freund, Ida, *The Study of Chemical Composition*, 61.

G.

Galvanometer, Adjustment of the d'Arsonval, for Ballistic Work, *F. Wenner*, 192.
Galvanometer, Some Properties of the Moving Coil, *W. P. White*, 371.
Gas Meters, A Method of Calibrating, *F. G. Benedict*, 294.
Gases and Vapors, The Absorption of Alpha-Rays in, *E. P. Adams*, 11.
Gates, Fanny Cook, Conduction of Air Due to Sulfate of Quinine, 45.
Geer, W. C., *The Study of Chemical Composition*, Ida Freund, 61.
Geyser in Atami, Japan, K. Honda and T. Terada, 300.
Grover, F. W., Mica Condensers as Standards of Capacity, 366.
Guthe, K. E., A New Determination of the E.M.F. of Clarke and Cadmium Standard Cells by Means of an Absolute Electrodynamometer 117.

H.

Hagenbach, *Atlas of Emission Spectra*, 62.
Hall, E. H., Thermoelectric Heterogeneity in Certain Alloys, 246.
Hartman, Leon W., Concerning the Temperature of the Nernst Lamp, 351.
Honda, K., On the Geyser at Atami, Japan, 300.
Hubbard, J. C., On the Conditions for Sparking at the Break of an Inductive Circuit, 129.
Hudson, C. F., The Freezing of Pure Liquids and Solutions Under Various Kinds of Positive and Negative Pressures and the Similarity between Osmotic and Negative Pressures, 257.

Hulett, Geo. A., Electrolytic Mercurous Sulphate as a Depolarizer for Standard Cells, 47.

Mercurous Sulphate and the Standard Cells, 321.

Humphreys, W. J., An Attempt to Explain the Cause of the Pressure-shift and the Broadening of the Spectrum Lines, 127.

The Mount Weather Research Observatory, 127.

Hygrometry, Methods of Soil, *E. Buckingham*, 248.

I.

Index of Refraction by the Interferometer, Measurement of, *J. C. Shedd and Philip Fitch*, 345.

Inductance, Self-, of Cylindrical Coils of any Number of Layers, on the Effect of Frequency upon the, *J. G. Coffin*, 365.

Inductances, Self- and Mutual-, On the Geometrical Mean Distances of Square Areas and Their Use in Calculating of, *Edw. B. Rosa*, 366.

Inductive Circuit, On the Conditions for Sparking at the Break of, *J. C. Hubbard*, 129.

Infra-red Emission Spectra, *W. W. Coblentz*, 1.

Infra-Red, Polarization in the, *A. H. Pfund*, 362.

Infra-Red, Selective Absorption in the, *A. H. Pfund*, 362.

Interferometer, Measurements of the Index of Refraction by the, *J. C. Shedd and Philip Fitch*, 345.

Ionization and Nucleation of Carbon Dioxide and Coal Gas, *Carl Barus*, 252.

Ionization in Flame Gases and Vapors, The Phenomena of, *F. L. Tufts*, 193.

Ives, Herbert E., Improvements in the Diffraction Process of Color Photography, 339.

K.

King, A. S. (Transl.), *Atlas of Emission Spectra*, Hagenbach and Konen, 62.

Konen, *Atlas of Emission Spectra*, 62.

L.

Longitudinal Vibrations Analogous to those of a Violin String, *Harvey N. Davis*, 121.

Low Temperatures, on the Velocity of Sound in Gases at, and the Ratio of the Specific Heats, *S. R. Cook*, 115.

Lynde, A. J., Effect of Pressure on Surface Tension, 181.

Luminescence, Studies of. VI. The Decay of Phosphorescence in Sidot Blende, *E. L. Nichols and Ernest Merritt*, 279.

M.

Magnetic Declinometer, A Self Recording, *W. G. Cady*, 249.

Magnetic Observatory Registration of Effects of Electric Cars over Twelve Miles Distant, *L. A. Bauer*, 300.

McLeod, C. H., Differential Temperature Records in Meteorological Work, 112.

Melting Points by Radiation Method, Determination of, *C. W. Waidner and G. K. Burgess*, 359.

Mercurous Sulfate and the Standard Cells, *Geo. A. Hulett*, 321.

Murcurous Sulfate as a Depolarizer for Standard Cells, Electrolytic, *Geo. A. Hulett*, 47.

Mercury Arc, Conductivity of the Vapor from, *C. D. Child*, 221.

Merritt, Ernest, *Die Physikalischen Eigenschaften der Seen*, Otto Freiherr von und zu Aufsess, 253.

Die Kathodenstrahlen, G.C. Schmidt, 253.

Electromagnetische Schwingungen und Wellen, Josef R. von Geitler, 253.

Populäre Schriften, Ludwig Boltzman, 255.

The Decay of Phosphorescence in Sidot Blende, 279.

Wireless Telegraphy, its History,

Theory and Practice, A. Fred'k. Collins, 63.

Metals, The Relative Conductivities Imparted to a Flame of Illuminating Gas by Vapor of Salts of the Alkali, *F. L. Tufts*, 113.

Meters, A Method of Calibrating Gas, *F. G. Benedict*, 294.

Mica Condensers as Standards of Capacity, *E. B. Rosa and F. W. Grover*, 366.

Mica Condensers, The Capacity of, *Anthony Zeleney*, 65.

Mount Weather Research Observatory, The, *W. J. Humphrey*, 127.

N.

Néculcea, E. (Fr. Transl.), *La théorie moderne des phènomènes physiques; radioactivité, ions, électrons*, 266.

Negative Pressures and Osmotic Pressures, Similarity of, *C. S. Hudson*, 257.

Nernst Lamp, Concerning the Temperature of the, *L. W. Hartman*, 351.

Nichols, E. L., *Atlas of Emission Spectra*, Hagenbach and Konen, Transl. by *A. H. King*, 62.

Die Electrischen Bogenlampen, J. Zeidler, 63.

Experimentelle Untersuchung von Gasen, Morris W. Travers, 62.

Lehrbuch der Physik, O. D. Chwolson, 60.

The Decay of Phosphorescence in Sidot Blende, 279.

Nocturnal Radiation, Temperature Records of, *H. T. Barnes*, 250.

Nucleation and Ionization of Carbon Dioxide and Coal Gas, *Carl Barus*, 252.

Nuclei, Condensation, *Carl Barus*, Presidential Address, 82.

O.

Observatory, The Mount Weather Research, *W. J. Humphreys*, 127.

Optical Properties of Carbon, *H. A. Clark*, 247.

Optical Rotation, On, *Herbert M. Reese*, 265.

Osmotic and Negative Pressures, Similarity of, *C. H. Hudson*, 257.

Ozone, Electrical Production of, *A. W. Ewell*, 111, 232.

P.

Pfund, A. H., Polarization in the Infra-red, 362.

Selective Reflection in the Infra-red, 362.

Phosphorescence, Decay of in Sidot Blende, *E. L. Nichols and Ernest Merritt*, 279.

Photography, Improvements in the Diffraction Process of Color, *H. E. Ives*, 339.

Physical Society, Abstracts, 45, 111, 192, 246, 320, 358.

Minutes, 80, 245, 357.

Pierce, Geo. W., Experiments on Resonance in Wireless Telegraph Circuits, 119 and 159.

Platinum Thermoelements, On the Constancy of, and Other Thermoelement Problems, *Walter P. White*, 372.

Polariscopic Measurements, Spectral Lines as Light Sources in, *Fred'k Bates*, 363.

Polarization in the Infra-red, *A. H. Pfund*, 362.

Potentiometer, A New, *H. B. Brooks*, 361.

Pressure, Freezing of Pure Liquids and Solutions under Various Positive and Negative, *C. S. Hudson*, 257.

Pressure Shift and Broadening of Spectrum Lines, An Attempt to Explain the Cause, *W. J. Humphreys*, 127.

R.

Radiation Method for Determining Melting Points, *C. W. Waidner and G. K. Burgess*, 359.

Radioactive Minerals, On the Relative Proportion of the Total Alpha-Ray of, Due to the Separate Constituents, *B. B. Boltwood*, 312.

Radioactivity of Thorium, *H. M. Dadourian*, 251.
Radiometer, Notes on the New form of, *W. W. Coblentz*, 358.
Radium, Magnetic and Electric Deflection of the Alpha-Rays from, *E. Rutherford*, 122.
Radium, Velocity and Ratio *e/m* for the Primary and Secondary Rays, *S. J. Allen*, 375.
Reese, Herbert M., On Optical Radiation, 265.
Reflection in the Infra-red, Selective, *A. H. Pfund*, 362.
Resonance in Wireless Telegraphy Circuits, Experiments on, *Geo. W. Pierce*, 119 and 159.
Righi, A., *The Modern Theory of Physical Phenomena* (Fr. Transl.), 256.
Same (German Transl.), 255.
Rosa, Edward B., Mica Condensers as Standards of Capacity, 366.
On the Geometric Mean Distances of Square Areas and their Use in the Calculations of Self- and Mutual-Inductances, 366.
The Ratio of the Electromagnetic and Electrostatic Units, 367.
Rotation, On Optical, *Herbert M. Reese*, 265.
Rutherford, E., Magnetic and Electric Deflection of Alpha-Rays from Radium, 122.
Some Properties of Alpha-Rays from Radium, 123.

S.

Schmidt, G. C., *Die Kathodenstrahlen*, 253.
Searle, G. F. C., *Mathematische Einführung in die Electronentheorie*, Dr. A. H. Bucherer, 52.
Serviss, S. B., Thermoelectric Heterogeneity of Certain Alloys, 246.
Shedd, John C., On the Measurement of the Index of Refraction by the Interferometer, 345.
Sidot Blende, Decay of Phosphorescence in, *E. L. Nichols and Ernest Merritt*, 279.
Smith, A. W., Damping of a Ballistic Galvanometer, 250.
Soil Hygrometry, Methods of, *E. Buckingham*, 248.
Soil Investigations, On the Use of Centrifugal Force in, *Lyman J. Briggs*, 125.
Sound, On the Velocity of, in Gases at Low Temperatures, and the Ratio of the Specific Heats, *S. R. Cook*, 115.
Sparking at the Break of an Inductive Circuit, *J. C. Hubbard*, 129.
Specific Heats, On the Velocity of Sound in Gases at Low Temperatures and the Ratio of the, *S. R. Cook*, 115.
Spectra, Infra-red Emission, *W. W. Coblentz*, 1.
Spectral Lines as Sources of Light in Polariscopic Measurements, *Fred'k Bates*, 363.
Spectrum Lines, An Attempt to Explain the Cause of the Pressure Shift and the Broadening of, *W. J. Humphreys*, 127.
Standard Cells, A New Determination of the E.M.F. of Clark and Cadmium, by Means of an Absolute Electrodynamometer, *K. E. Guthe*, 117.
Standard Cells, Electrolytic Mercurous Sulfate as Depolarizer for, *Geo. A. Hulett*, 47.
Standard Cells, Mercurous Sulfate and, *Geo. A. Hulett*, 321.
Standards of Capacity, Mica Condensers as, *E. B. Rosa and F. W. Grover*, 366.
Studies in Luminescence, VI., The Decay of Phosphorescence in Sidot Blende, *E. L. Nichols and Ernest Merritt*, 279.
Sulfate of Quinine, Conduction of the Air Due to, *Fanny C. Gates*, 45.
Surface Tension, Effects of Pressure on, *C. J. Lynde*, 181.

T.

Temperature of the Nernst Lamp, *L. W. Hartman*, 351.

Temperature Records in Meteorological Work, Differential, *C. H. McLeod and H. T. Barnes*, 112.

Temperature Records of Nocturnal Radiation, *H. T. Barnes*, 250.

Tension, Effect of Pressure on Surface, *C. J. Lynde*, 181.

Terada, T., On the Geyser at Atami, Japan, 300.

Thermoelectric Heterogeneity of Certain Alloys, *E. H. Hall, L. L. Campbell, S. B. Serviss*, 246.

Thermoelement, On the Constancy of the Platinum, and other Thermoelement Problems, *W. P. White*, 372.

Thermostat Operable at Room Temperatures, An Electrically Controlled, *Lyman J. Briggs*, 126.

Thin Films, The Optical Properties of, *Wm. B. Cartmel*, 115.

Thorium, The Radioactivity of, *H. M. Dadourian*, 251.

Travers, Morris W., *Experimentelle Untersuchung von Gasen*, 62.

Tufts, F. L., The Phenomena of Ionization in Flame Gases and Vapors, 193.

The Relative Conductivities Imparted to the Flame of Illuminating Gas by Vapors of the Alkali Metals, 113.

U.

Units, on the Ratio of the Electromagnetic and Electrostatic, *E. B. Rosa and N. E. Dorsey*, 367.

V.

Vibrations, Longitudinal, Analogous to Those in a Violin String, *H. N. Davis*, 121.

von Geitler, Josef Ritter, *Electromagnetische Schwingungen und Wellen*, 253.

von Aufsess, Otto Freiherr, *Die Physikalischen Eigenschaften der Seen*, 253.

W

Waidner, C. W., On the Determination of Melting Points by Radiation Method, 359.

Water of Crystallization and Water of Constitution, *W. W. Coblentz*, 368.

Wave Detector, Electrolytic, *L. W. Austin*, 364.

Weather Research Observatory, The Mount, *W. J. Humphreys*, 127.

Wenner, Frank, The Adjustment of the D'Arsonval Galvanometer for Ballistic Work, 192.

White, W. P., The Constancy of Platinum Thermoelements, and Other Thermoelement Problems, 372.

Some Properties of the Moving Coil Galvanometer, 371.

Wireless Telegraph, Experiments on Resonance in Wireless Telegraph Circuits, *G. W. Pierce*, 119 and 159.

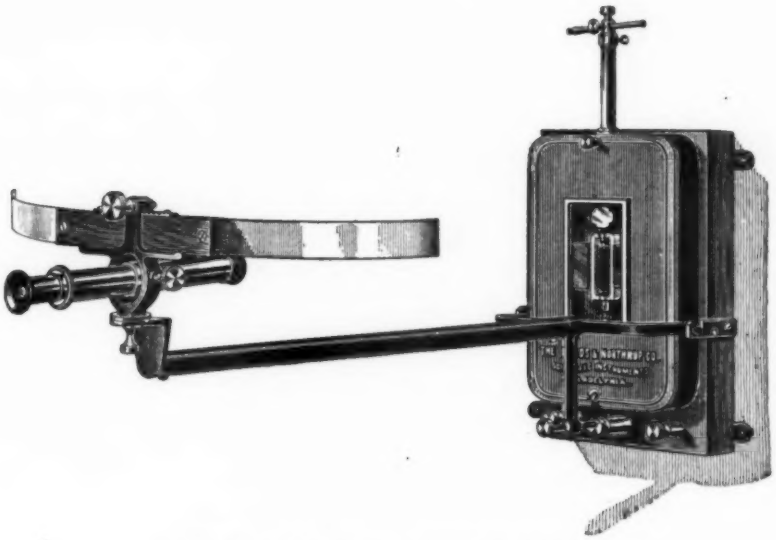
Z.

Zeidler, J., *Die Electrischen Bogenlampen*, 63.

Zeleny, Anthony, The Capacity of Mica Condensers, 65.

JAN 19 1917

LEEDS & NORTHRUP
Electrical Measuring Instruments



TYPE H D'ARSONVAL GALVANOMETERS

These instruments will be found eminently satisfactory for most classes of Galvanometer work. They have good sensibility, positive zero, are quick in action, and are dead beat. They are easy to set up and keep in good working order; they have ample coil clearance and the suspensions are protected against breakage by a new device. To meet various requirements, they are furnished in several forms for wall and table use.

Send for complete descriptive pamphlet on D'Arsonval Galvanometers and our new Catalogue of Electrical Measuring Instruments.

THE LEEDS & NORTHRUP CO.

4901 Stenton Ave., - Philadelphia, Pa.

Among Standard Books on Electricity and Magnetism

BARNETT.—Elements of Electro-Magnetic Theory. By S. J. BARNETT, Ph.D., Professor of Physics in the Tulane University, New Orleans, La.
480 pp. 8vo, $3.00 *net;* postage 20 cts.

CURRY.—Electro-Magnetic Theory of Light. By CHARLES EMERSON CURRY, Ph.D. Part I.
xv+400 pp. 8vo, gilt top, cloth, 42 fig., $4.00 *net.*

FRANKLIN and WILLIAMSON.—The Elements of Alternating Currents. By W. S. FRANKLIN and R. B. WILLIAMSON. *Second Edition,* rewritten and Enlarged.
c. 11 + 333 p. 8vo, cloth, $2.50, *net;* postage 15 cts.

HOBART.—Electric Motors, Continuous Current Motors, and Induction Motors. By H. M. HOBART.

JACKSON.—A Text-Book on Electro-Magnetism, and the Construction of Dynamos. By DUGALD C. JACKSON, B.S., C.E. Professor of Electrical Engineering, University of Wisconsin.
12mo, cloth, $2.25, *net;* postage 12 cts.

————Alternating Currents and Alternating Current Machinery. By DUGALD C. JACKSON, C.E., University of Wisconsin, and JOHN P. JACKSON, M.E., Pennsylvania State College.
pp. xvii + 729, 12mo, cloth, price, $3.50, *net;* postage 17 cts.

————Elementary Electricity and Magnetism. By D. C. JACKSON, University of Wisconsin, and J. P. JACKSON, State College, Pennsylvania.
Illustrated. Cloth, 12mo, $1.40 *net;* postage, 15 cts.

RIGHI.—Modern Theory of Physical Phenomena. Radio-Activity, Ions, Electrons. By AUGUSTO RIGHI, University of Bologna. Authorized Translation by AUGUSTUS TROWBRIDGE, University of Wisconsin.
xiii+165 pp. 12mo, illustrated, cloth, $1.10 *net.*

RUTHERFORD.—Radio-Activity. By E. RUTHERFORD, McGill University, Montreal. viii+399 pp. 8vo, illustrated, cloth, $3.50 *net.*

SWENSON and FRANKENFIELD.—Testing of Electro-Magnetic Machinery and Other Apparatus. By BERNARD VICTOR SWENSON and BUDD FRANKENFIELD. Vol. I.
xxiii+420 pp. 8vo, il., cl., $3.00 *net.*

TALBOT and BLANCHARD.—The Electrolytic Dissociation Theory, with Some of Its Applications: An Elementary Treatise for the Use of Students of Chemistry. By HENRY P. TALBOT, Ph.D., Professor of Inorganic and Analytical Chemistry, and ARTHUR A. BLANCHARD, Ph.D., Instructor in Organic Chemistry at the Massachusetts Institute of Technology.
v+84 pp. 8vo, cloth, $1.25 *net.*

THOMPSON.—Elementary Lessons in Electricity and Magnetism. By SILVANUS P. THOMPSON, D.Sc.
16mo, cloth, $1.40, *net;* postage 14 cts.

TURNER and HOBART.—The Insulation of Electric Machinery. By HARRY WINTHROP TURNER, Associate, A.I.E.E., and HENRY METCALF HOBART, M.I.E.E., M.A.I.E.E. With 162 Illustrations.
xvi+297 pp. 8vo, illustrated, cloth, $4.50 *net.*

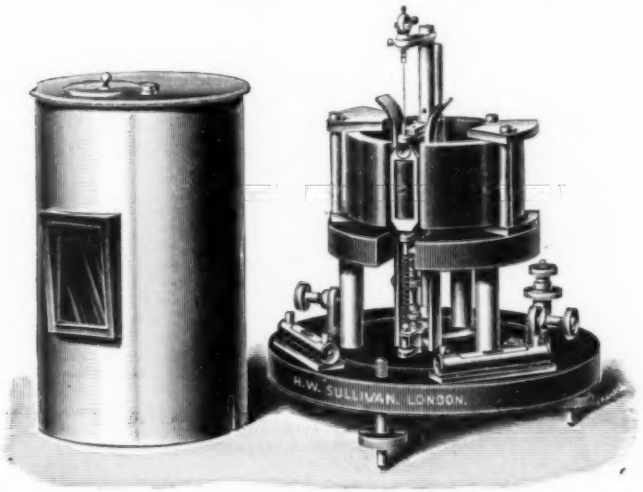
WEBSTER.—The Theory of Electricity and Magnetism. By A. G. WEBSTER, A.B. (Harv.), Ph.D. (Berol.) Assistant Professor of Physics, Clark University.
pp. xii+576, 8vo, cloth, price, $3.50, *net;* postage 21 cts.

WHITTAKER'S Electrical Engineer's Pocket Book. Edited by KENELM EDGECUMBE, with 161 illustrations.
Second edition, 8+541 p. Leather, $1.50 *net.*

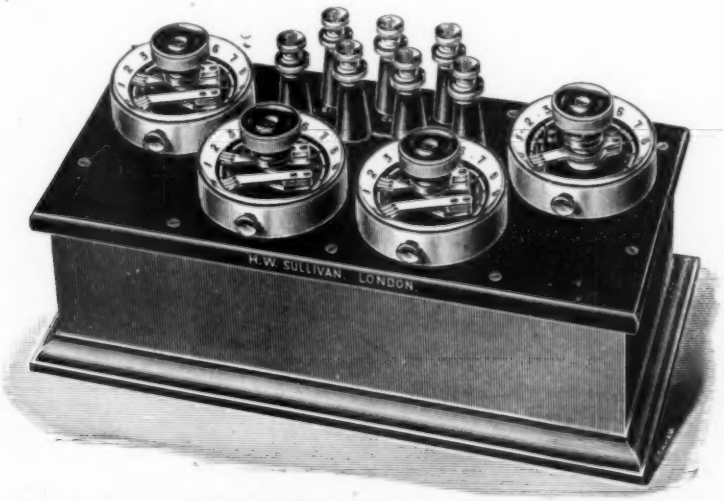
THE MACMILLAN COMPANY, Publishers, New York.

SULLIVAN'S

UNIVERSAL GALVANOMETERS AND SHUNTS . . .



As used by the leading Governments, by all the Submarine Cable Companies and by numerous Electric Supply and Manufacturing Corporations, Universities and Educational Institutions throughout the world.



For particulars of this and other special apparatus, apply to the

Sole Maker, H. W. SULLIVAN

19, Great Winchester Street, LONDON, E. C. (England)

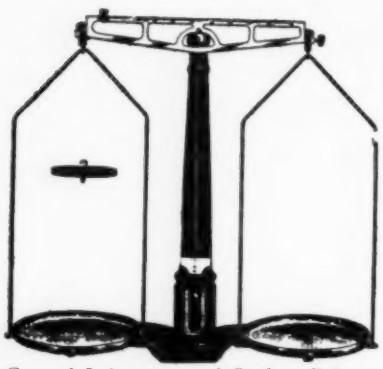
N. B.—No Agents **to whom all communications should be addressed direct**

MORSE TWIST DRILL AND MACHINE CO.

NEW BEDFORD, MASS., U. S. A.

... Manufacturers of ...

Increase Twist and Constant Angle Drills, Chucks, Reamers, Milling Cutters, Taps, Dies and Machinists' Tools



General Laboratory and Student Balance

WM. GAERTNER & CO.

Astronomical and Physical Apparatus

5347 and 5349 Lake Avenue, CHICAGO

SPECIALTIES

Standard Apparatus of new and improved designs, Astronomical Telescopes, Spectroscopes, Micrometers, Michelson Interferometers and Echelon Spectroscopes, Reading-microscopes and Telescopes, Heliostats, Dividing Engines, Comparators, General Laboratory Apparatus, Universal Laboratory-supports.

Special attention paid to the construction of instruments for original investigation after our own or furnished designs.

Wagner Electric Manufacturing Co.

ST. LOUIS, U. S. A.

The most interesting and only commercially successful form of Single Phase Alternating Current Power Motor so far produced in this country, is that built by this Company. One or more of these motors should prove a very valuable adjunct to every College Laboratory, and we invite correspondence with University or College authorities on the subject. For such applications we are prepared to make liberal price concessions.

We also manufacture transformers for all sorts of service, and Indicating Switchboard Instruments, samples of which we will be glad to place in College Laboratories at reduced prices.

Have you our various Bulletins, descriptive of these lines?

Factory and General Offices: St. Louis, U. S. A.

RICHARD MÜLLER-URI

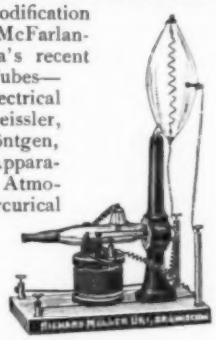
Braunschweig (Germany)

PARIS, 1900, SILVER MEDAL.

Manufacturer of BLOWN GLASS FOR SCIENTIFIC PURPOSES

Vacua Scale

Chas. R. Cross' Vacua Scale—Harris J. Ryan's Modification of Braun's Cathode-Rays Tube, extra large—McFarlan-Moore's Vibrator Apparatus—Transformer, Tesla's recent Model, without Oil-insulation, and Vacuum Tubes—Spectrum Tubes, improved recent models—Electrical Tubes after Arons, Bruan, Crookes, Ebert, Geissler, Goldstein, Hittorf, Lecher, Lenard, Puluj, Röntgen, Tesla, Wien, Zehender—Photoelectric Cells and Apparatus—Selenium Cells—Electrometer—Exner's Atmospheric-Electricity-Apparatus—Dry Piles—Mercurical Arc-Lamps—Current Demonstration Apparatus—Compendium, Stan'd Series of Geissler Tubes.



McFarlan-Moore Apparatus

Sole Maker and Furnisher of Patented Constructions: N.

215124 Spectrum Tube for common and end-on view

200160 Electroscope, improved special Compound-Insulation

160542 Heat Propagation-Apparatus, after Kränzlins

134775 Research of Germination Apparatus, after O. Reinke

115874 Röntgen Tube, Müller-Uri Model for Dermatologists

112885 Möller and Schmidt, Electrical Current Apparatus

Braun's Tube (Ryan)

Apparatus for Chemical Work

Best Chemical Glassware and Porcelain—Bohemian Glass and Jena-Normal Glasses—Crystal Thermometers for projection and for the most high and low Temperatures.

St. Louis 1904 Centennial Exhibition

PHYSICAL APPARATUS

FOR LECTURE AND DEMONSTRATION PURPOSES

Manufactured by MAX KOHL, Chemnitz

IMPORTED AT LOWEST PRICES by

EIMER & AMEND

18th STREET and THIRD AVENUE, NEW YORK

Manufacturers and Importers of

C. P. CHEMICALS AND REAGENTS

CHEMICAL APPARATUS, Etc.

Agents for the

Optical Goods made by

FRANZ SCHMIDT & HAENSCH, CARL ZEISS and others

Curie's Radium and Apparatus for the Study of Radio-Activity

GALVANOMETERS

of every *degree* of *Sensibility* suitable for

Resistance, Insulation Testing, Ballistic Work, Etc.

The illustration shows one of our various types, the **PATENT DUDDELL THERMO-GALVANOMETER** an instrument of no self-induction, and measuring currents as small as *20 Amperes*.

Price of Duddell Thermo-Galvanometer with 4 and 100 Ohm Heaters £15.10.0 $75.00

Additional Heaters each 7/6–12/6 . . . . . $1.80–$3.00

Descriptive Leaflets sent on application to

The Cambridge Scientific Instrument Company, Limited

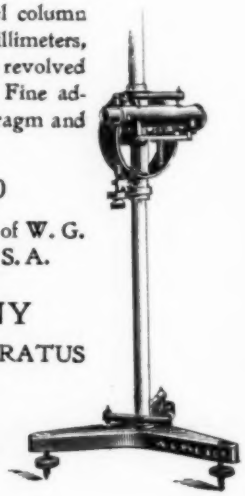
CAMBRIDGE, ENGLAND.

SHORT TABLE CATHETOMETER

Manufactured by W. G. PYE & COMPANY, Cambridge (England).

A reliable, rigid and serviceable instrument at a moderate price.
Constructed throughout on geometric lines.

The annular carriage supporting the telescope slides on a steel column 75 cm. high, turned and ground true, and with a scale 50 cm. in millimeters, engraved. It rests on a fixed pin in a sliding collar and may be revolved in a true horizontal plane. Coarse adjustment to 1/20th mm. Fine adjustment to 1/100 mm. Telescope has Ramsden eye-piece, diaphragm and cross wires.



Duty Free price F. O. B. Philadelphia : $67.50

Descriptive pamphlet of the above, and complete catalogue of W. G. Pye & Co.'s manufactures mailed free on request. Agents for U. S. A.

ARTHUR H. THOMAS COMPANY

OPTICAL INSTRUMENTS and LABORATORY APPARATUS

S. W. Cor. 12th & Walnut Streets, Philadelphia

We make a specialty of duty free importation of instruments and apparatus from all reliable European makers at factory prices and exceptionally economical rates. Write for particulars.

American Instrument Company

"American" voltmeters and ammeters are the product of the best engineering skill, and the best manufacturing equipment in America.

They are of the permanent magnet moving coil type which is the recognized standard for D. C. work. They embody new features of much value that make them superior to all other instruments.

Bulletin 50 describes switchboard types, Models 1 and 2:—explaining in detail their points of genuine merit. Write for a copy.

These instruments are specially suited for use in Engineering and Physical laboratories.

JAMES G. BIDDLE

GENERAL SALES AGENT

1114 Chestnut Street **Philadelphia**

"Duty Free" Importations

Now is the time to select new apparatus for next year's work, and to place orders, so that it will surely be on hand at the right time.

Many instruments must necessarily come from abroad. For a college to import direct is often very troublesome. With over *10 years experience* in this work I am prepared to handle all orders most advantageously to you; —that is with *lowest cost, quickest delivery* and *least trouble.* Also I carry a large supply of latest catalogues from the best foreign makers; any of which will be sent free to interested scientists. Often they are very helpful in selecting apparatus. My services cost *you* nothing, as I am paid a small commission from the *manufacturer.*

Write for *Bulletin 590,*—a list of Catalogues of Interest to Scientific Men. Also ask for *Biddle's Bulletin.*

JAMES G. BIDDLE

1114 Chestnut Street, Philadelphia

Special agent for:—American Instrument Co., Electric Storage Battery Co., Roentgen Mfg. Co., Cambridge Scientific Instrument Co., Otto Wolff, Siemens & Halske, Pulsometer Engineering Co., Wm. Gaertner & Co., Max Kohl, Sciété Genevoise, Hartmann & Braun, Robert W. Paul, Kelvin & Jas. White, Ltd., Carl Zeiss, etc., etc.

Queen Instruments

QUEEN UNIVERSAL DECADE BRIDGE AND RHEOSTAT

A new compact, moderate priced Resistance Box and Wheatstone Bridge, embodying many improvements in design and construction. A few important features:

Series, Multiple, or Combination Rheostat Connections.

Reversible Bridge Arms.

Interior Connections Engraved on Rubber Top.

Coils of Manganin Wire.

Write for further details.

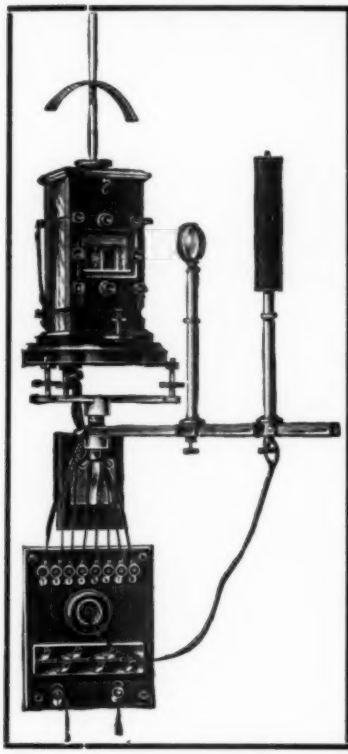
ELECTRODYNAMOMETERS PHOTOMETERS

X-RAY APPARATUS

Queen & Co., Inc.

Cor. Arch and Eighth Sts.,

PHILADELPHIA, PA., U. S. A.



LEPPIN & MASCHE

17, Engelufer Berlin, S. O., GERMANY

Factory of **Scientific Instruments**

Astatic Mirror Galvanometer

With Bracket and Switch Board
For Electric Light or Gas

COMPLETE SET - - $75.00

Athen 1904: Gold Medal
St. Louis 1904: Grande Price

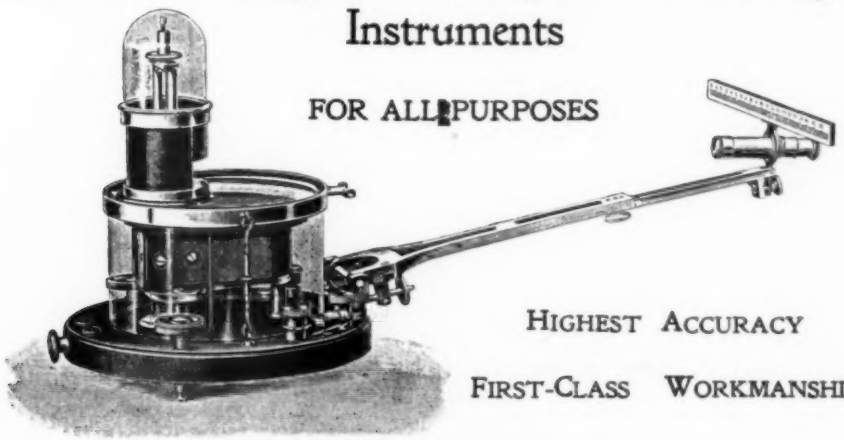
HARTMANN & BRAUN, A.-G.

Frankfort-on-Main (Germany)

——Manufacturers of——

Electrical, Magnetic and Optical Measuring Instruments

FOR ALL PURPOSES



HIGHEST ACCURACY

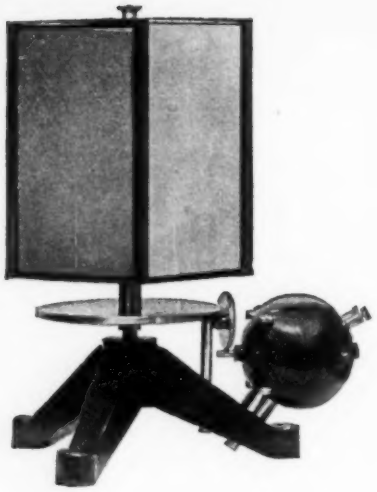
FIRST-CLASS WORKMANSHIP

DEAD-BEAT MOVING COIL GALVANOMETER
WITH READING TELESCOPE AND SCALE

MOTOR-DRIVEN

ROTATING MIRRORS

110 volt a. c. or d. c.



INTERNATIONAL INSTRUMENT CO.

CAMBRIDGE, MASS., U. S. A.

..Makers of High-Grade Scientific and Laboratory Apparatus..

JUST READY

AN INTRODUCTION TO

ASTRONOMY

By FOREST RAY MOULTON, Ph.D.,

Assistant Professor of Astronomy in the University of Chicago,
Author of "An Introduction to Celestial Mechanics."

Cloth, 8vo, 550 pages. Just ready.

An attempt has been made in this volume to give an introductory account of the present state of the science of astronomy. The aim has been to present the subject so that it shall be easily comprehended by the student without mathematical or extensive scientific training, and so that he may obtain from it not only some knowledge of scientific achievement, but also something of the spirit which inspires scientific work. Numerous brief historical references have been introduced to show by what steps the marvellous results of astronomical investigations have been reached.

PUBLISHED BY

THE MACMILLAN COMPANY, 64-66 Fifth Avenue, N.Y.

DR. STEEG & REUTER

Optisches Institut

Homburg, v. d. Hohe, GERMANY

Norrenberg's Polariscope

APPARATUS AND PREPARATIONS for investigations of POLARIZATION, Interference, Diffraction, Fluorescence and Phosphorescence of light.

FILMS OF NATURAL AND ARTIFICIAL CRYSTALS for studying the optical properties of crystallized bodies in polarized light.

PREPARATIONS of calcspar (NICOL PRISMS), Quartz, Rocksalt, Selenite and Mica.

ACCESSORIES FOR SPECTROMETERS as: Solid and hollow prisms. Amici or Janssen prisms. Wernicke's fluid prisms for direct vision and deflected rays.

PLANE-PARALLEL PLATES.

STANDARD TEXT-BOOKS ON MECHANICS

BOYNTON.—Application of the Kinetic Theory of Gases, Vapors, Pure Liquids, and the Theory of Solutions. By WILLIAM PINGRAY BOYNTON, University of Oregon. *10+288 pages. 8vo. Cloth, $1.60 net.*

DUFF.—Elementary Experimental Mechanics (Kinematics, Dynamics, Elastic Solids and Fluids). By A. WILMER DUFF, Worcester Polytechnic Institute, Worcester, Mass. *7+257 p. 12mo, cl., $1.60 net.*

LONEY.—The Elements of Hydrostatics. By S. L. LONEY, Professor of Mathematics at the Royal Holloway College. *xxv+248 pages. $1.00 net.*

Key. *16mo. Cloth. 146 pages. $1.25 net.*

The Elements of Statics and Dynamics. In two parts.

Part I. Elements of Statics. *16mo. viii+296 pages. $1.25 net.*
Part II. Elements of Dynamics. *16mo. xviii+188 pages. $1.00 net.*

The same in One Volume, *$1.90 net.*

REEVE.—The Thermodynamics of Heat-Engines. By SIDNEY A. REEVE, Professor of Steam-Engineering at the Worcester Polytechnic Institute. *12mo. Cloth. xi+316 pages. $2.60 net.*

SLATE.—The Principles of Mechanics. An Elementary Exposition for Students of Physics. By FREDERICK SLATE, Professor of Physics in the University of California. *12mo. Cloth. x+299 pages. $1.90 net.*

ZIWET.—Elements of Theoretical Mechanics. By ALEXANDER ZIWET, University of Michigan. *8vo. Cloth. ix+494 pages. $4.00 net.*

THE MACMILLAN COMPANY, 64-66 Fifth Ave., New York

Siemens & Halske Aktiengesellschaft

Ammeters, Voltmeters, Wattmeters, Dynamometers, Ohmmeters, Potentiometers, Normal Resistances, Resistance Boxes, Box Bridges, Slide Bridges, Thomson Bridges, Condensers, Moving Coil Galvanometers, Moving Needle Galvanometers, Reading Telescopes, Electrometers, Electrostatic Voltmeters, Cable Sets, Permeameters, Photometers, Hefner Lamps, Tachometers, Keys, etc.

Carl Zeiss Optical Works

Spectroscopes, Spectrometers, Refractometers, Comparators, Stereo-Comparators, Interference and Schlieren Apparatus, Microscopes, Microscopic Objectives, Microphotographic Apparatus, Projecting Lanterns, Binocular and Monocular Telescopes, Astronomical and Astrophotographic Objectives, Field Glasses and Stereoscopic Telescopes, Stereoscopic Telemeters, Photographic Lenses, Cameras, Stereoscopes and Verants, Telescopic Gun Sights, etc.

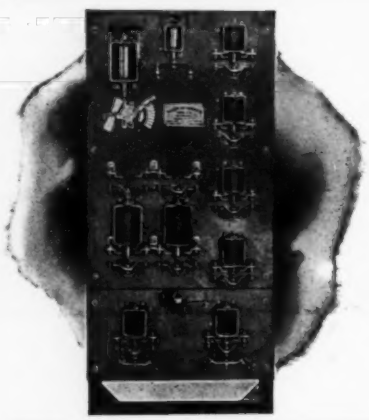
For Literature and Quotations address

THE SCIENTIFIC SHOP

ALBERT B. PORTER

Scientific Instruments **326 Dearborn St., Chicago**

Special Controllers for Special Conditions



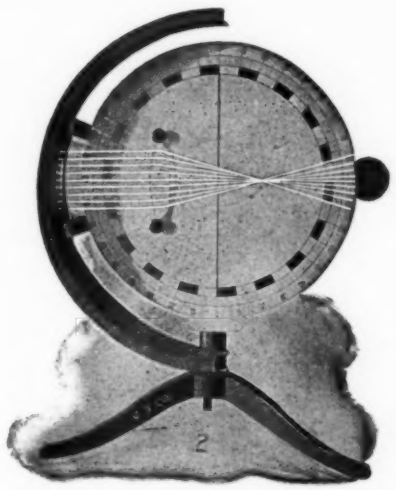
IT sometimes happens that our standard apparatus is not suitable in all respects for conditions of service to be met. In cases of this kind we design and build apparatus that is suitable.

A large engineering force whose time is devoted solely to solving problems of electric control, and the largest factory devoted to the exclusive building of electric controllers give us unusual advantages in doing this sort of work.

THE CUTLER-HAMMER MFG. CO.

MILWAUKEE, WIS.

NEW YORK	CHICAGO	PITTSBURG	BOSTON
136 Liberty St.	1232 Monadnock Bldg.	322 Frick Bldg	176 Federal St.



FOCUSING BEAM OF PARALLEL RAYS

Hartl Optical Disc

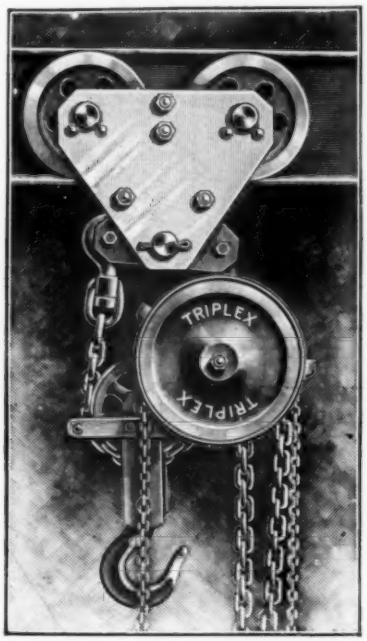
For the determination of all Laws of Elementary Optics

This apparatus displaces much of the usual equipment for teaching optics and awakens an interest not usually found in the subject. The Hartl Optical Disc is now in the laboratories of many Universities, College, Normal and High Schools throughout the country. Complete description in catalog "O".

Our facilities for Duty Free Importations of Physical and Chemical Apparatus are at your disposal. Close prices and prompt service will be given from the leading foreign manufacturers.

Central Scientific Company

14-28 Michigan St., **CHICAGO, U. S. A.**



This shows a Yale & Towne

Triplex Block

on a plain I-Beam trolley.

Such installations are very flexible in cost and application. They are adapted to a large variety of lifting uses both outside and inside.

For further information see our chain block catalog.

THE YALE & TOWNE MFG. CO.

9 Murray Street, New York

Diffusing Reflectors

A New Departure Secures Increased Efficiency

GIVE broader illuminated area than any other. Secure softtened light, agreeable appearance, are white on outside, may be tinted to modify tone of light. Combine effectiveness of prismatic type with diffusive action of porcelain type, retain agreeable appearance of latter, whilst avoiding obtrusiveness of former.

Used in
All Rapid Transit
Subway Stations

ILLUMINATING ENGINEERING CO.

201 East Sixteenth Street, New York City

E. L. ZALINSKI, *Consulting Engineer on Illumination, Etc.*
Refers to C. C. Haight, A. W. Brunner, Wm. H. Aiken, Architects.

MAX KOHL, Chemnitz, Saxony

MANUFACTURER OF

PRECISION MECHANICAL INSTRUMENTS

LARGEST ESTABLISHMENT OF ITS KIND

Furnishes as a specialty complete outfits for Physical and Chemical Laboratories; Physical Apparatus and Instruments; Apparatus after Tesla, Hertz, Marconi, etc. Complete outfits for X-Ray work. Purest Radium bromid of 1,200,000 × activity.

NOVELTY INDUCTION COILS, with Changeable Self-Induction, which allow soft medium hard or hard X-Ray Tubes to be worked with an electrolytic Interrupter with any current.

Profusely Illustrated catalogues with 3,500 Illustrations, directions, quotations, references, etc., in German, English or French furnished without any charge.

World's Fair St Louis, 1904, Grand Prize and Gold Medal.
World's Fair, Chicago, 1893: 2 Diplomas; World's Fair, Paris, 1900.
Orders may be addressed direct to MAX KOHL, CHEMNITZ, or by the mediation of
Messrs. EIMER & AMEND, NEW YORK, 18th Street and Third Ave., or of
Mr. JAMES G. BIDDLE, PHILADELPHIA, 1114 Chestnut Street.
ARTHUR H. THOMAS CO., PHILADELPHIA, S. W. Cor. Walnut and Twelfth Streets.

JUST READY

PHYSICAL OPTICS

By ROBERT W. WOOD

Professor of Experimental Physics in the
Johns Hopkins University.

Cloth, 8vo, 546 pp., $3.50 net. With 325 figures.

Intended to supply an advanced text-book in English, suitable for general class-work, and covering the recent and remarkable discoveries in the field of magneto-optics. Special stress has been laid on the experimental side.

THE MACMILLAN COMPANY, - 64-66 Fifth Ave., N. Y.

Recent Imported Books on Physics

ALLSOP.—Practical Electric Light Fitting. A Treatise on the Wiring and Fitting up of Buildings Deriving Current from Central Station Mains, and the Laying down of Private Installations. By F. C. ALLSOP. Revised and Enlarged. With 242 illustrations. *viii+289 p. 12mo, il., cl., $1.50 net.*

HADLEY.—Magnetism and Electricity for Students. By H. E. HADLEY, B.Sc., (Lond.), Associate of the Royal College of Science, London, Headmaster of the School of Science, Kidderminster. *x+575 p. 12mo, cl., $1.40 net.*

HERBERT.—Telegraphy: A Detailed Exposition of the Telegraph System of the British Post Office. By J. E. HERBERT. 509 Illustrations. *912 pp., sm. cr. 8vo, $2.60 net.*

JEANS.—The Dynamical Theory of Gases. By J. H. JEANS, M.A., Fellow of Trinity College, Cambridge. *vi+352 p. Imperial 8vo, cl., $4.50 net.*

MAZZOTTO. Wireless Telegraphy and Telephony. By Prof. DOMENICO MAZZOTTO. Translated from the original Italian, by S. R. BOTTONE. With 253 illustrations. *12+416 p. 12mo, il., cl., $2.00 net.*
Whittaker's Practical Handbooks.

POOLE.—The Practical Telephone Handbook. By JOSEPH POOLE, Technical Staff, Head Office National Telephone Co., Ltd. 473 Illustrations. Third Edition, entirely rewritten and greatly enlarged. *533 pp., $2.00 net.*

ROUTH.—The Advanced Part of a Treatise on the Dynamics of a System of Rigid Bodies. Being Part II of a Treatise on the whole Subject. With numerous examples. By EDWARD JOHN ROUTH. Sixth Edition. Revised and Enlarged. *xiv+484 p. 8vo, cl., $3.75 net.*

RUTHERFORD.—Radio-Activity. By E. RUTHERFORD, D.Sc., F.R.S.C., Macdonald Professor of Physics, McGill University, Montreal, Second Edition, with Much Additional Matter. *14+580 p. 8vo, cl., $4.00 net.*

STOKES.—Mathematical and Physical Papers. By the Late SIR GEORGE GABRIEL STOKES, Bart., Sc.D. LL.D., D.C.L., Professor of Mathematics in the University of Cambridge. Reprinted from Original Journals and Transactions, with Brief Historical Notes and Reference. Vol. V. *25+370 p. 8vo, cl., $3.75 net.*

TWELVETREES.—Concrete Steel: A Treatise on the Theory and Practice of Reinforced Concrete Construction. By W. NOBLE TWELVETREES, Late Vice-President of the Civil and Mechanical Engineers' Society, Author of "Structural Iron and Steel." With Numerous Illustrations, Diagrams and Tables. *12+218 p. $1.90 net.*

WALKER.—The Analytical Theory of Light. By JAMES WALKER, M.A., Christ Church, Oxford; Demonstrator of Physics in the Clarendon Laboratory, Oxford. *15+416 p. 8vo, cl., $5.00 net.*

WHETHAM.—The Theory of Experimental Electricity. By WILLIAM CECIL DAMPIER WHETHAM, M.A., F.R.S., Fellow of Trinity College, Cambridge. *11+334 p. 8vo, il., cl., $2.50 net.*

WHITTAKER.—A Treatise on the Analytical Dynamics of Particles and Rigid Bodies. With an Introduction to the Problem of Three Bodies. By E. T. WHITTAKER, M.A., Fellow and Lecturer of Trinity College, Cambridge. *13+414 p. Imperial 8vo, cl., $4.00 net.*

PUBLISHED BY

THE MACMILLAN COMPANY

64-66 Fifth Avenue, New York.

Standard Text-Books on General Physics

ANDREWS and HOWLAND.—Elements of Physics. By ERNEST J. ANDREWS, Instructor in Science in the Robert A. Waller High School, Chicago, and H. N. HOWLAND, Instructor in Physics in the South Division High School, Chicago. Including a Manual of Experiments. 439 pp. Cloth, 12mo, $1.10, *net.*

SLATE.—Physics: A Text-book for Secondary Schools. By FREDERICK SLATE, University of California. Cloth, 12mo., $1.10, *net;* postage, 12c.

CAJORI.—A History of Physics. In its Elementary Branches, including the Evolution of Physical Laboratories. By FLORIAN CAJORI, Ph.D., Professor in Physics in Colorado College, Author of "A History of Mathematics," "A History of Elementary Mathematics," etc. Cloth, Cr., 8vo, $1.60, *net;* postage 15 cts.

CREW.—The Elements of Physics for Use in High Schools. By HENRY CREW, Ph.D., Northwestern University.
Second Edition, Revised. Cloth, $1.10, *net;* postage 12 cts.

CREW and TATNALL.—A Laboratory Manual of Physics.
(Companion to the above) 90 cts.

CHRISTIANSEN.—Elements of Theoretical Physics. By PROFESSOR C. CHRISTIANSEN, University of Copenhagen. Translated by W. F. MAGIE, Ph.D., Professor of Physics, Princeton University. Cloth, 8vo, $3.25, *net;* postage 17 cts.

MATTHEWS and SHEARER.—Problems and Questions on Physics. By CHARLES P. MATTHEWS, M.E., Purdue University, and JOHN SHEARER, B.S., Cornell University. 8vo, cloth, pp. 247 + 4, price, $1.60, *net;* postage 13 cts.

STEWART.—Lessons on Elementary Practical Physics. By BALFOUR STEWART, A.M., LL.D., F.R.S., and W. W. HALDANE GEE. Cloth, 12mo.

Vol. I. **General Physical Processes.** $1.50, *net;* postage 9 etc.
Vol. II. **Electricity and Magnetism.** $2.25, *net;* postage 12 cts.
Vol. III. Part I. **Practical Acoustics.** $1.10, *net;* postage 9 cts.
Part II. **Heat and Light.** *In Preparation.*

NICHOLS.—Laboratory Manual of Physics and Applied Electricity. Arranged and Edited by EDWARD L. NICHOLS, Professor of Physics in Cornell University. In two volumes.

Vol. I. **Junior Course in General Physics.** By ERNEST MERRITT and FREDERICK J. ROGERS. Cloth, 8vo, $3.00, *net;* postage 15 cts.

Vol. II. **Senior Courses and Outlines of Advanced Work.** By GEORGE S. MOLER, FREDERICK BEDELL, HOMER S. HOTCHKISS, CHAS. P. MATTHEWS, and THE EDITOR. Cloth, 8vo, $3.25, *net;* postage 15 cts.

NICHOLS and FRANKLIN.—The Elements of Physics. By EDWARD L. NICHOLS and W. S. FRANKLIN.

Volume I. Mechanics and Heat, $1.90 *net;* Volume II. Electricity and Magnetism, $1.90, *net;* Volume III. Sound and Light, $1.50, *net.*

A large proportion of the students for whom primarily this Manual is intended are preparing to become engineers, and special attention has been devoted to the needs of that class of readers.

Books published at NET prices are sold by booksellers everywhere at the advertised NET prices. When delivered from the publishers, carriage, either postage or expressage, is an extra charge.

THE MACMILLAN COMPANY, New York: 64-66 Fifth Ave.

BOSTON CHICAGO SAN FRANCISCO